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PRELIMINARY IDENTIFICATION OF GRADE AND RECOVERY RELATIONSHIPS AT THE DURHAM MINE CONCENTRATOR, PRINCE WILLIAM, NEW BRUNSWICK

by

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DISCLAIMER

An independent consultant has performed a review of grade and recovery relationships based on the data obtained from in-plant sampling, administered by the Department of Natural Resources and Energy. The data has been summarized in this report with acknowledgement to the developers. The conclusions and recommendations of this study rely on the accuracy of sampling procedures and standard industrial testing procedures.

This study is to be used only for the purpose of assisting Dominion Explorers Inc. with the optimization of metal recovery at the Durham Mines Concentrator. The study has only identified concepts which may improve on metal recoveries. Process conditions for optimum recovery are subject to additional studies.

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REPORT NUMBER: 8809

Table of Contents

1.0 EXECUTIVE SUMMARY 1

2.0 INTRODUCTION 2
- 2.1 Study Objectives and Scope 2
- 2.2 Background 3
- 2.3 Test Program Methodology 5

3.0 PRELIMINARY BENCH-SCALE STUDIES 6
- 3.1 Grade and Recovery of Antimony Batch Flotation 6
- 3.2 Batch Flotation Kinetics 8
- 3.3 Gravity Separation Tests 8

4.0 PLANT GRADE AND RECOVERY 11
- 4.1 Base Case 11
- 4.2 Regrind of Rougher Tails 19
- 4.3 Regrind of Scavenger Concentrate and Cleaner Tails 19
- 4.4 Unit Operations - Mass Balance 22
- 4.5 Summary of Recovery Versus Particle Size Relationships 27
- 4.6 Mineralogy of Major Process Streams 29

5.0 CONCLUSIONS 36

6.0 RECOMMENDATIONS 41

7.0 REFERENCES 43

APPENDIX I 44

List of Tables and Figures

Table 3.1	Bench Scale Flotation Tests	Page 7
Figure 3.1	Batch Flotation Kinetics for Antimony Flotation	Page 9
Table 3.2	Gravity Separation - Mozley Mineral Separator	Page 10
Figure 4.1	Process Flowsheet for Base Case Tests	Page 12
Figure 4.2	Process Flowsheet for Regrind (Test C)	Page 13
Figure 4.3	Process Flowsheet for Regrind (Test D,F,G)	Page 14
Figure 4.4	Particle Size Distribution for Flotation Feed	Page 15
Figure 4.5	Antimony Metal Distribution for Flotation Feed	Page 16
Table 4.1	Overall Antimony Grade and Recovery	Page 17
Figure 4.6	Grade & Recovery of Antimony Distribution of Metal in Flotation Feed	Page 18
Figure 4.7	Grade & Recovery of Antimony with a Regrind	Page 20
Figure 4.8	Overall Antimony Grade & Recovery with Regrind	Page 21
Figure 4.9	Particle Size Analysis of Regrind Cyclone Streams	Page 23
Figure 4.10	Grade & Recovery of Antimony with a Regrind	Page 24
Figure 4.11	Recovery Versus Particle Size (Test A)	Page 25
Figure 4.12	Recovery Versus Particle Size (Test H)	Page 26
Figure 4.13	Grade & Recovery Vs Particle Size	Page 28
Table 4.2	Distribution of Minerals in Process Streams	Page 30
Figure 4.14	Mineral Distribution (Test H)	Page 31
Figure 4.15	Mineral Distribution (Test G)	Page 32
Figure 4.16	Mineral Distribution (Test E)	Page 34
Figure 5.1	Antimony Recovery as a Function of Feed & Tails	Page 37
Figure 5.2	Ore Value Vs. Metal Production	Page 40
Figure 6.1	Conceptual Flowsheet (Recovery Limitations)	Page 42

1.0 EXECUTIVE SUMMARY

This report includes a summary of in-plant testing and an assessment of antimony recovery limitations at the Dominion Explorers Inc., Durham Mine Concentrator. The test work administered under the Mineral Processing Investigations Program of the Federal-Provincial Mineral Development Agreement, was performed during the period June, 1986 to March, 1987. An average recovery of 88.5% was determined for each test with metal losses attributed to a combination of the following:

- Particles greater than 75 micron contain non-liberated stibnite which is lost to tails.
- Overgrinding of the ore increases the distribution of antimony in the particle size range of minus 25 micron. A limitation on recovery in the less than 25 micron range may be due to extremely fine antimony grains which are not liberated and/or slow floating antimony minerals.
- Minor concentrations of iron-antimony sulfides (ie. berthierite) that occur in the ore are not being recovered in the flotation circuit.

Particle size distribution is a prominent factor limiting the recovery of antimony. An optimum grade and recovery relationship was determined to be in the particle size range of 25 to 75 microns. Process modifications have been recommended based on particle size and liberation data. The cost of future development studies should be based on potential increases in concentrator revenues. For example, under the current operating conditions at a concentrate value of U.S. $20/MTU, an increase in recovery from 88.5% to 90% would result in increased revenue of CDN $223,000 to CDN $287,000.

2.0 INTRODUCTION

2.1 Study Objectives and Scope

An in-plant test program was designed by the Department of Natural Resources and Energy (DNRE) to quantify recovery limitations at the Dominion Explorers Inc. antimony concentrator. The essential first step was to identify and quantify separation limitations so that technical and economic factors could be considered prior to process modifications.

In-plant separation data was derived by DNRE at various time intervals under optimum steady state operating conditions. This report includes an assessment of this data while addressing the following general tasks:

- o A technical review of the test program results based on particle size analysis, mass balance and mineralogical data of various process streams.
- o Review of economic criteria and recommendations for future studies on the optimization of antimony separation and recovery.

The overall objective was to identify and quantify certain characteristics of the ore and/or certain process conditions which limit optimum grade and recovery. In the long term, it is anticipated that this study will contribute to enhancing the mineral value of the mine. Identification of the process limitations will benefit future process development by providing a sound basis for the implementation of either novel or existing processing concepts.

The scope of this assessment is to present and discuss data from the following:

A. Preliminary bench-scale grinding and batch flotation tests on run-of-mine ore and gravity separation tests on secondary cyclone underflow.

B. Assays, particle size analysis and antimony particle size distribution data on various process streams for seven individual in-plant tests.

C. Mass balance calculations for both dry solids and antimony, based on particle size distribution for various flowsheet configurations.

D. Mineral identification and size liberation based on three particle size ranges for each of feed, final concentrate and final tails.

2.2 Background

Antimony sulphide (Sb_2S_3) is smelted to produce antimony metal which, when subjected to fuming or sublimation, recombines with oxygen to yield antimony trioxide (Sb_2O_3). Various add-on processing technologies for antimony sulphide concentrate have been summarized by Thibault [1].

The primary demand for antimony is in the trioxide form where it is employed as a flame retardant in various aspects of the automobile and aircraft industries as well as in certain household fabrics. Some 12.3 tonnes of trioxide [2] representing 38.6% of total demand were consumed in the United States in 1984. Growth forecast for consumption in this category was 3.6% per annum. Antimony metal is used primarily as an alloy to impart hardness to metals such as those used in bearing manufacturing.

The cyclical nature of antimony consumption is compounded by erratic overproduction by such major primary producers as China. Accordingly, the price of antimony will ultimately depend on Chinese marketing practices.

The Durham Antimony Mine, located in Prince William, New Brunswick, has a long history of production. Antimony ore has been mined intermittently from different ore zones since 1963. Today, the Durham Mine is North America's only antimony sulphide mine concentrator, owned and operated by Dominion Explorers Inc. Ore is upgraded by flotation in the Durham Concentrator to meet world market specifications.

Antimony generally occurs as stibnite (Sb_2S_3) in the mill feed, ranging from 2.5% to 4.5% Sb. Some 20 tonnes per hour of ore is ground to 57% -200 mesh by two overflow ball mills in series. Metal recovery varies from 88.0% to 92.0% in the

production of a concentrate grade averaging 65% Sb. The standard flowsheet of the flotation circuit consists of:

- Six rougher cells using two cells as a primary rougher and the remaining four cells as a secondary rougher.
- Rougher concentrate is upgraded in a 3-cell first cleaner, 2-cell second cleaner bank of cells. Concentrate flow is counter current with final product reporting from the second cleaners.
- First cleaner tails and rougher tails are treated in a six cell scavenger circuit. Scavenger concentrate is recycled to the secondary rougher with scavenger tails reporting as final tailings.

Process development at the Durham Concentrator has been focused on the optimization of recovery and the ability to maintain steady state operations. In most sulphide concentrators, the operating process variables are selected to remove impurities from concentrate at the expense of recovery. Arsenic may be regarded as the predominant impurity in the Durham ore, but the rejection of arsenic to tailings has not been reported as a limitation to recovery.

Prior to this study, Lakefield Research [3] was contracted by the Durham Mine Division (under the Mineral Investment Stimulation Program) to study the effect of reagent selection on antimony recovery. Bench-scale batch flotation testing did not match the grade-recovery performance of Durham's concentrator and tailings losses were attributed to non-stibnite antimony mineralization for particles less than 20 micron. It was further concluded that lead nitrator as an activator with potassium amyl xanthate as a collector were ineffective in recovering iron-rich antimony minerals. Quantification of the antimony loss due to particle size and mineralogical limitations was beyond the scope of the Lakefield study.

Discussions between DNRE officials and the management of the Durham concentrator resulted in the decision to proceed with an in-plant study designed to quantify mineralogical and particle size recovery limitations. Under the Canada-New Brunswick Mineral Development Agreement, technical staff was appointed and made responsible for the administration of in-plant sampling and compilation of data. Sampling was carried out during the operation of the

concentrator from June, 1986 to March, 1987. The analysis of the test results is the subject of this report.

2.3 Test Program Methodology

The test program was designed to characterize the separability of the ore with existing process unit operations and process operating conditions. Operating variables such as reagent dosage, throughput of ore, and flotation time were not varied. To assess the effect of regrind on recovery, certain process streams were recycled to the grinding circuit. To determine the long-term relative change in ore separability characteristics, eight hour composite samples were collected under steady state conditions. The following is a description of the sampling campaign:

June 10, 1986 (8 am - 4 pm)

TEST A: Standard flowsheet. Data used to establish a base case for identification of antimony loss by detailed mass balance calculations.

September 15, 1986 (8 am - 4 pm)

TEST B: Standard flowsheet. Data used for comparison to base case TEST A and as a base case for the regrind flowsheet of TEST C.

TEST C: Recycle of secondary rougher tails to grinding circuit. Data used to assess possible improvements in antimony recovery.

October 16, 1986 (8 am - 4 pm)

TEST D: Recycle of scavenger concentrate and cleaner tails. Data used to assess possible improvement in antimony recovery with this flowsheet. Mineralogy of antimony on feed, concentrate and final tails.

TEST E: Standard flowsheet. Data used for comparison to TESTS A and C, and to assess a variation in antimony liberation compared to TEST D.

December 9, 1986 (8 am - 4 pm)

TEST F: Recycle of scavenger concentrate and cleaner tails. Data used to assess the performance of recycle cyclone.

March 19, 1987 (8 am - 4 pm)

TEST G: Recycle of scavenger concentrate and cleaner tails. Data used to assess variability in separation and modifications to recycle cyclone.

TEST H: Standard flowsheet. Data used for comparison to TESTS A, C and E, and as a base case for TEST G.

3.0 PRELIMINARY BENCH-SCALE STUDIES

Prior to in-plant testing, bench-scale tests were carried out to determine the ore separability characteristics. Ore separation efficiency was based on antimony grade-recovery relationships for various particle size fractions. Since concentrate grade is largely unaffected by contaminants such as arsenic and lead, the rejection efficiencies of these metals were not assessed.

3.1 Grade and Recovery of Antimony Batch Flotation

Batch rougher flotation bench tests were performed using one kilogram samples of ore. Reagent addition and flotation parameters simulated plant operating conditions. The ore was ground in separate tests to 73% and 94% -200 mesh. By increasing the fine content in the ground ore, the effect of antimony metal distribution on grade and recovery was determined. Test results are summarized in Table 3.1.

For a constant reagent dosage and a variation in fines concentration, it was found that antimony grade and recovery is directly related to particle size. Although reagent dosage is related to mineral particles, surface area test conditions were not optimized for the substantial increase in fines concentration. The grade/recovery relationship of the bench-scale flotation tests did not resemble the primary rougher in the production circuit. However, the following qualitative observations are based on a relative assessment of the two tests:

- An increase in the amount of antimony less than 25 micron results in a lower recovery. Since the reagent dosage is based on plant grind of 57%-200 mesh, the bench-scale flotation recovery could theoretically be optimized by reagent dosage. Thus, the variation in grind characteristics will influence recovery at constant reagent dosages.

TABLE 3.1

BENCH SCALE BATCH FLOTATION TESTS

	TEST B-1	TEST B-2
GRIND	73% -200 mesh	94% -200 mesh
HEAD GRADE	3.70% Sb	4 61% Sb
AMOUNT OF + 297 u	15.80%	4.30%
FLOTATION RECOVERY	81.34%	75.63%
CONCENTRATE GRADE	31.00% Sb	25.00% Sb
DISTRIBUTION OF METAL IN FLOTATION:		
75-297 u	3.10	0.50
25-75 u	29.80	15.81
-25 u	67.10	83.69
GRADE/RECOVERY OF METAL IN FLOTATION:		
75-297 u	38.44/31.06	20.99/39.33
25-75 u	45.06/79.94	26.88/60.68
-25 u	27.05/88.65	24.70/79.78

NOTE:

(1) All flotation tests were carried out on -297 micron material.

(2) Reagent dosages for each test were (as per plant operation):

0.31 g/tonne collector
0.36 g/tonne MIBC
0.78 g/tonne lead nitrate

(3) Flotation and aeration time were 2 minutes for each test.

(4) In-plant recoveries were 79.7% on primary rougher with grades of 45.3% Sb.

- An optimum concentrate grade of antimony for each test was found to be in the range of 25 to 75 micron.

3.2 Batch Flotation Kinetics

A batch rougher flotation test was done using a one kilogram sample of ore. Reagent additions were identical to plant operating dosages and the grind was approximately 60% -200 mesh. Samples were taken at various time intervals from 0 to 180 seconds. An antimony distribution was determined for each interval and the results are summarized in Figure 3.1.

The flotation of stibnite was relatively fast compared to base metal sulphide flotation. In order to achieve a rougher grade of 35% to 45% Sb, residence time of fifteen to thirty seconds was required. Longer residence times were required to achieve an optimum recovery of the slower floating antimony, which was determined to be in particles finer than 25 micron.

3.3 Gravity Separation Tests

A sample of cyclone underflow from the secondary grind was used for gravity separation tests. The purpose of the tests was to qualitatively assess the presence of recoverable antimony in the cyclone underflow. The difference in the specific gravity of silica and that of stibnite allows gravity separation to occur using a Mozley Mineral Separator. Test results are summarized in Table 3.2.

The gravity separation tests were used to indicate whether middling or liberated antimony minerals are present in the cyclone underflow. In Test A, the 100 to 2000 micron size fraction, about 31.5% of the antimony can be recovered at a grade of 36.5% Sb. Test B indicates that a higher recovery can be achieved at lower grades. It is uncertain if a final concentrate grade can be produced from the cyclone underflow without a regrind. Additional testing (including cyclone efficiency tests) would be required to assess the net improvement in plant recovery by gravity separation of antimony from cyclone underflow.

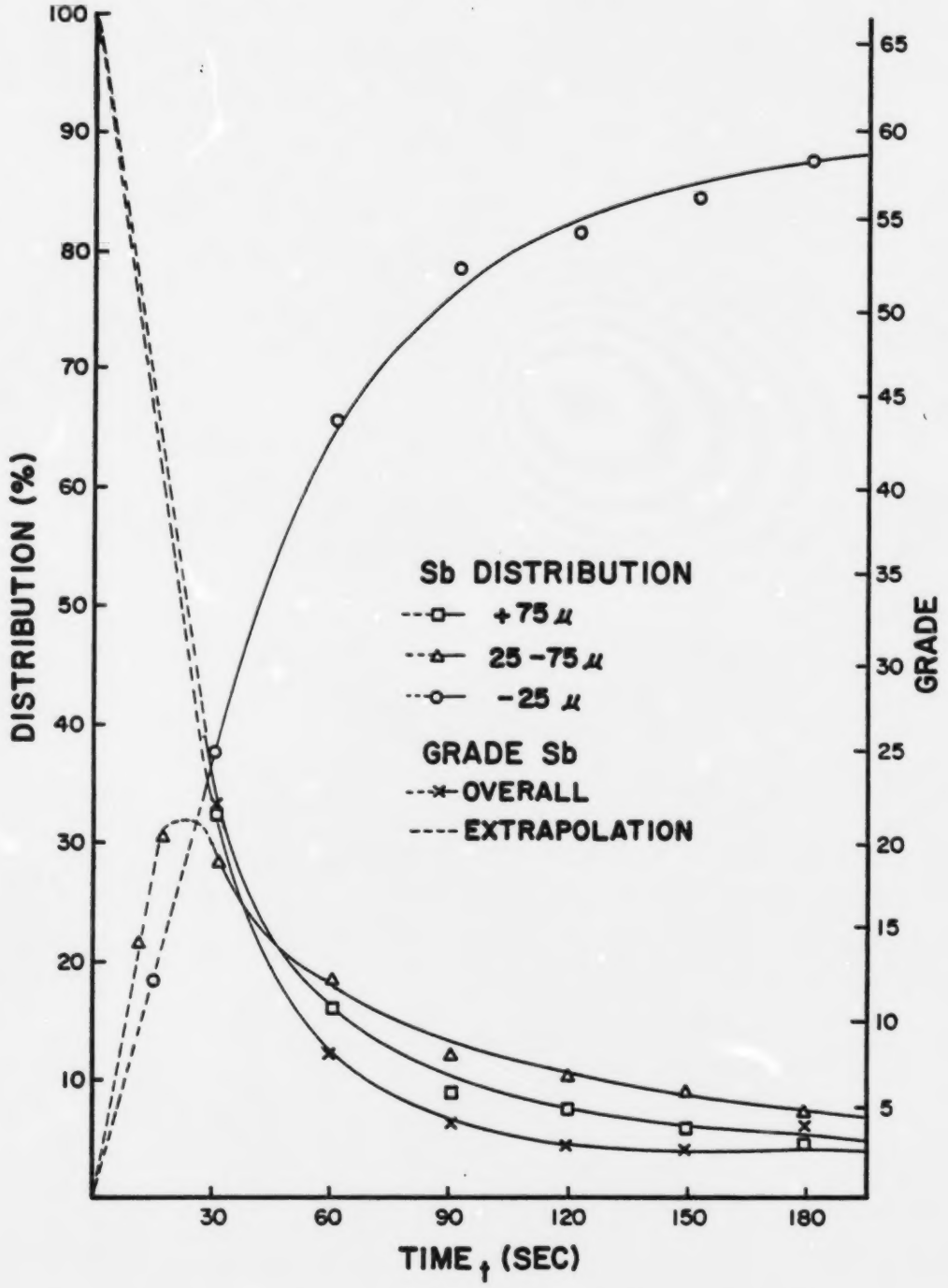

FIGURE 3.1: Batch flotation kinetics (concentrate Sb distribution versus time) for antimony flotation. Head grade 4.6% Sb, reagent dosage as per Table 3.1, grind 60% -200 mesh.

TABLE 3.2

GRAVITY SEPARATION - MOZLEY MINERAL SEPARATOR
SECONDARY GRIND CYCLONE UNDERFLOW

SAMPLE ASSAY 4.59% Sb

	WEIGHT (g)	ASSAY (%Sb)	METAL DISTRIBUTION (%)	CONCENTRATE GRADE (%Sb)	CUMULATIVE RECOVERY (%)
TEST A [100-2000 u, slope 1.75, stroke 2.5", 72 RPM, 1.5 L/min wash water]					
TAILS 1	61.0	1.11	17.0	9.4	83.0
TAILS 2	24.6	3.83	13.6	22.7	59.4
MIDDLING	7.0	15.90	27.9	36.5	31.5
CONCENTRATE	3.5	36.50	31.5	-	-
TEST B [same as TEST A with 0.5 L/min wash water]					
TAILS 1	50.0	0.78	10.6	6.6	89.4
TAILS 2	32.2	1.84	16.1	15.2	73.3
MIDDLING	7.1	8.99	17.3	19.3	56.0
CONCENTRATE	10.6	19.50	56.0	-	-
TEST C [same as TEST B]					
TAILS 1	42.0	0.75	9.6	7.5	90.4
TAILS 2	24.8	2.69	20.3	15.3	70.1
MIDDLING	5.0	14.20	21.6	15.8	48.6
CONCENTRATE	10.0	16.00	48.6	-	-
TEST D [-100 u, slope 1.75, stroke 3.5", 96 RPM, 2.5 L/min wash water]					
TAILS 1	95.8	5.94	57.4	35.7	42.6
TAILS 2	7.9	39.70	31.5	27.8	11.1
CONCENTRATE	4.0	27.80	11.2	-	-
TEST E [same as TEST D]					
TAILS 1	89.9	6.91	74.4	32.7	26.6
TAILS 2	3.8	37.70	16.9	25.9	8.7
CONCENTRATE	2.8	25.90	8.9	-	-

4.0 PLANT GRADE AND RECOVERY

The overall grade and recovery of antimony was determined based on various particle size ranges of plant feed, concentrate and final tails. A total of eight sampling campaigns were conducted on three different process flowsheet configurations. The base process flow is the standard operating flowsheet of the Durham Concentrator and is shown in Figure 4.1. In attempts to regrind antimony middling from rougher tails and from scavenger concentrate/cleaner tails, the standard flowsheet was modified as illustrated respectively in Figures 4.2 and 4.3.

A coarser particle size distribution of flotation feed resulted from recycling solids from the flotation circuit to the secondary ball mill. The difference in particle size distribution for each test is illustrated in Figures 4.4 and 4.5. It is believed that the decrease in the grinding mill residence time and the decreased efficiency of the secondary classification resulted in a coarser flotation feed.

The overall grade and recovery of antimony did not vary significantly for each flowsheet configuration. As summarized in Table 4.1, the concentrate grade varied from 64.1% to 65.9% Sb with recovery variations from 87.6% to 88.9%. Flowsheet variations and changes in flotation feed particle size distribution failed to produce a noticeable change in the separation efficiency. The reason for this will be reviewed in this section.

4.1 Base Case

For the standard flowsheet, the optimum grade and recovery was found to be in the particle size range of 35 to 55 microns. As illustrated in Figure 4.6, about 60% of the antimony was less than 35 micron and about 24% was greater than 55 micron. The lower recoveries in the -35 and +55 micron size range result in lower overall recovery of antimony.

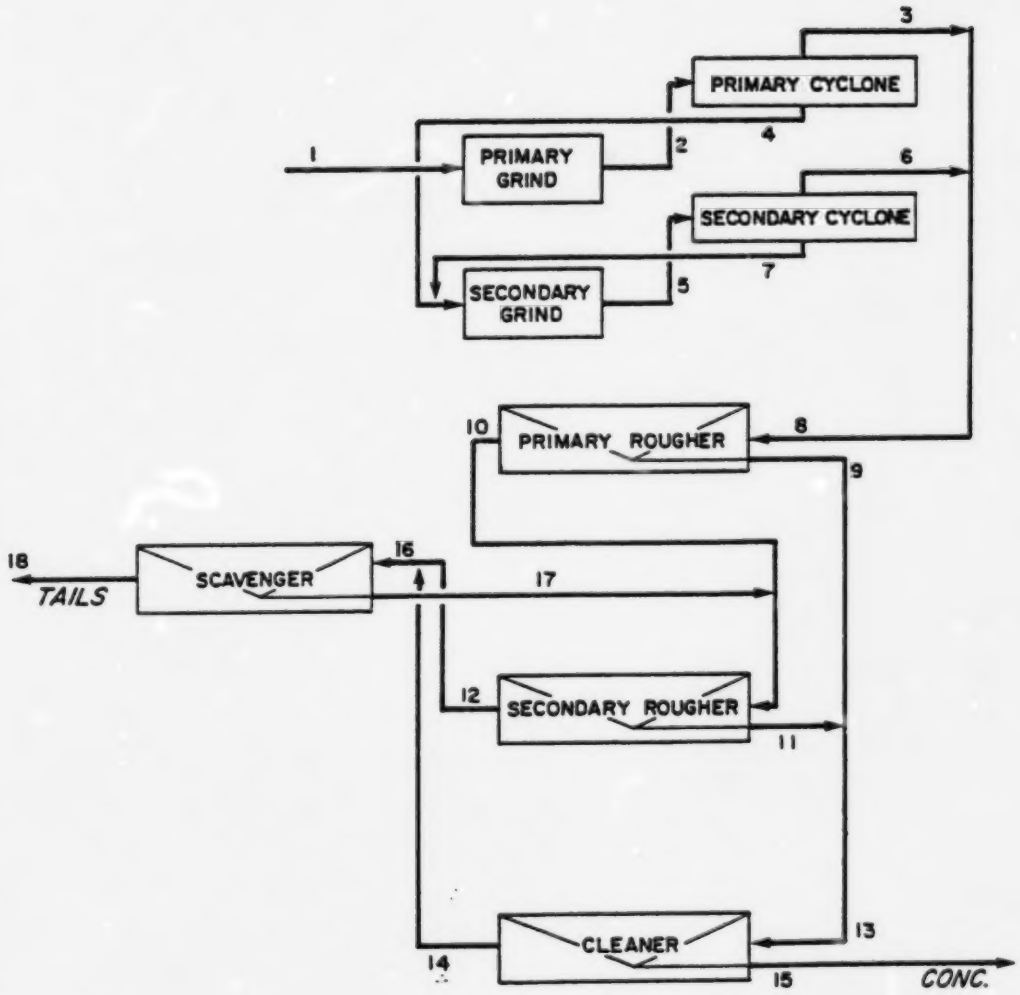

FIGURE 4.1: Process flowsheet configuration for base case Tests A, B, E, and H.

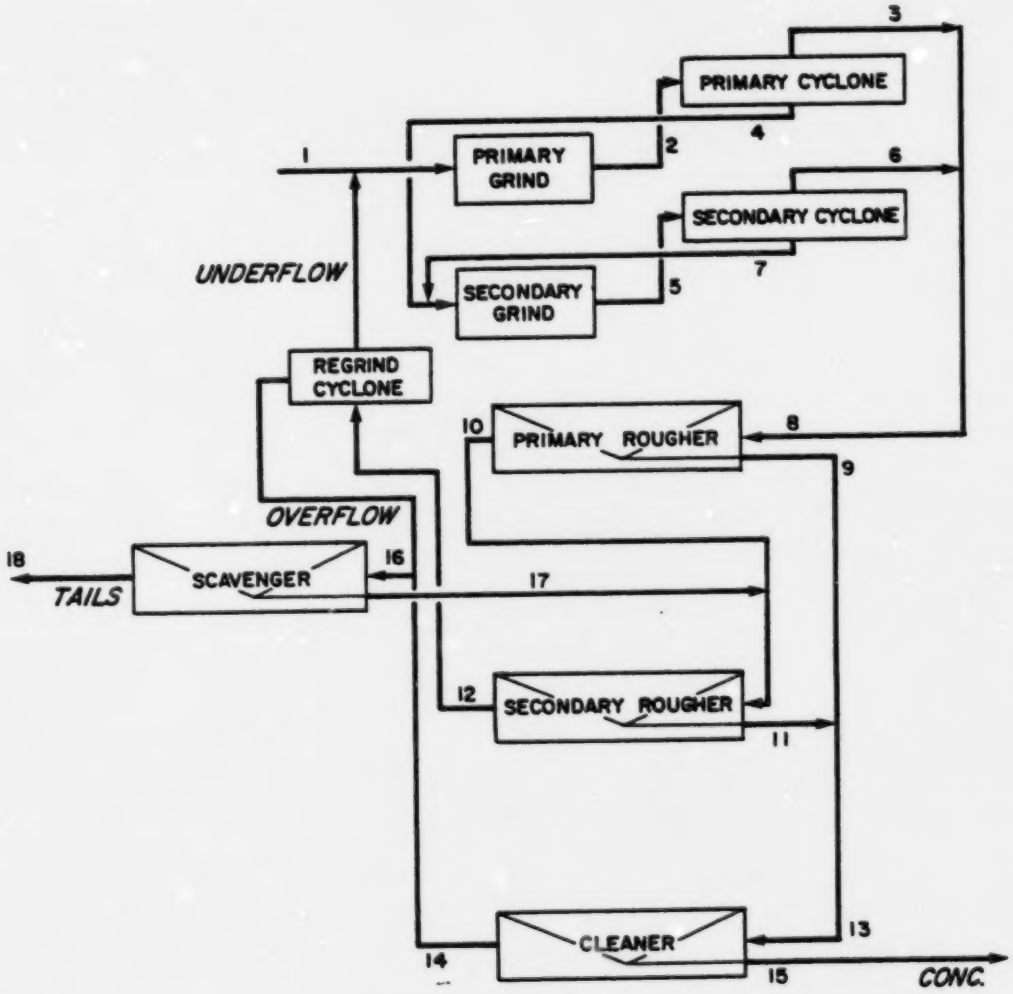

FIGURE 4.2: Process Flowsheet configuration for regrind of rougher tails; Test C.

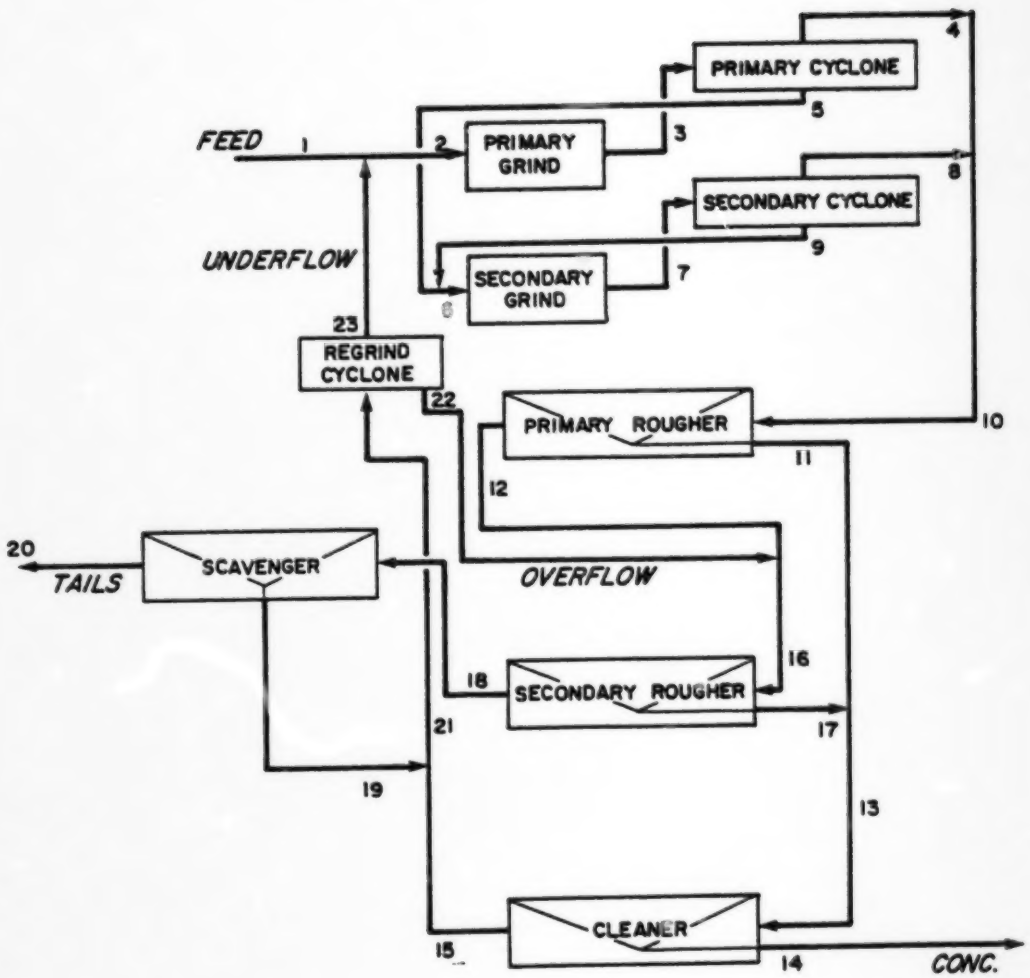

FIGURE 4.3: Process flowsheet configuration for regrind of cleaner tails and scavenger concentrate; Tests D, F, and G.

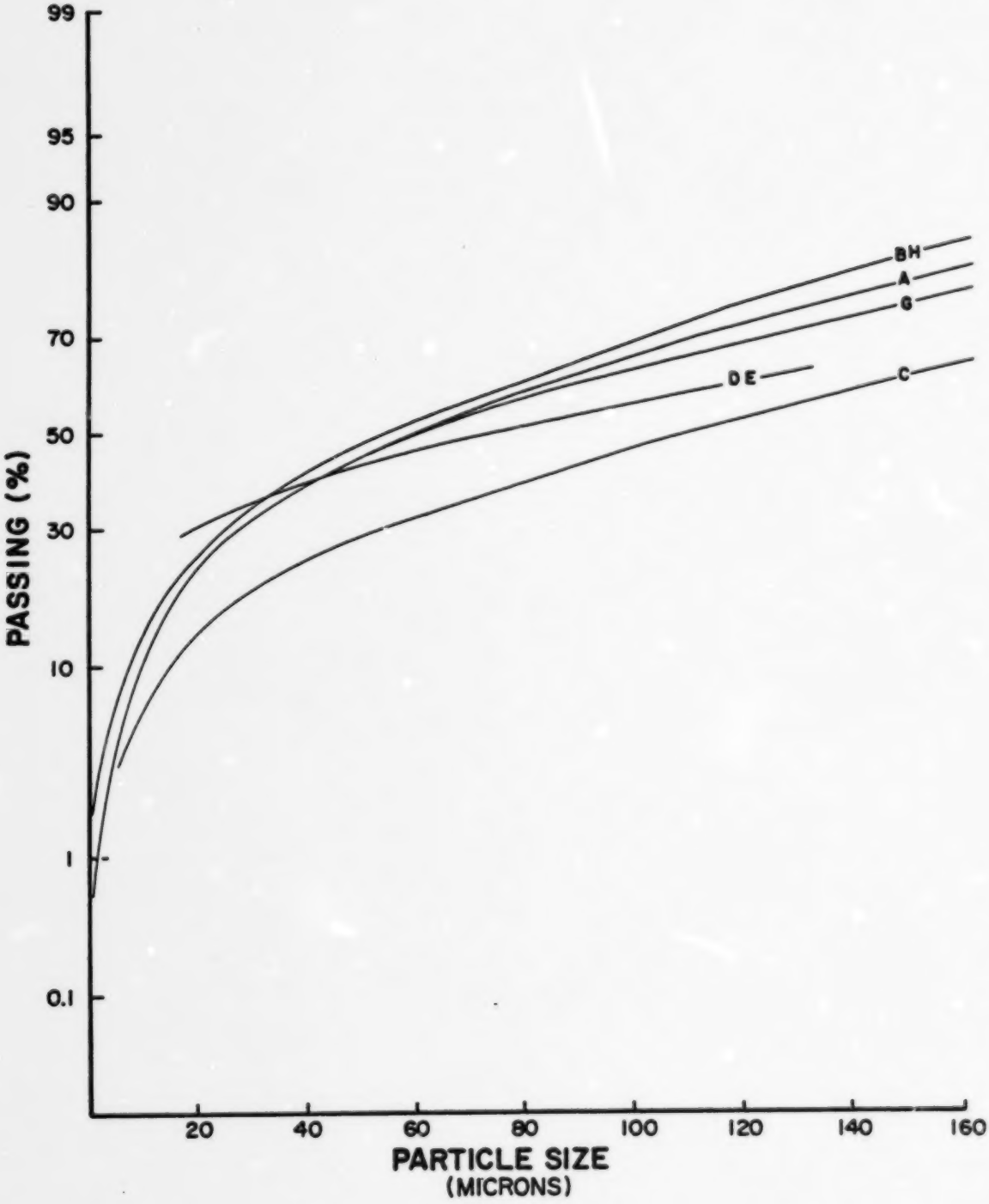

FIGURE 4.4: Particle size distribution of flotation feed.

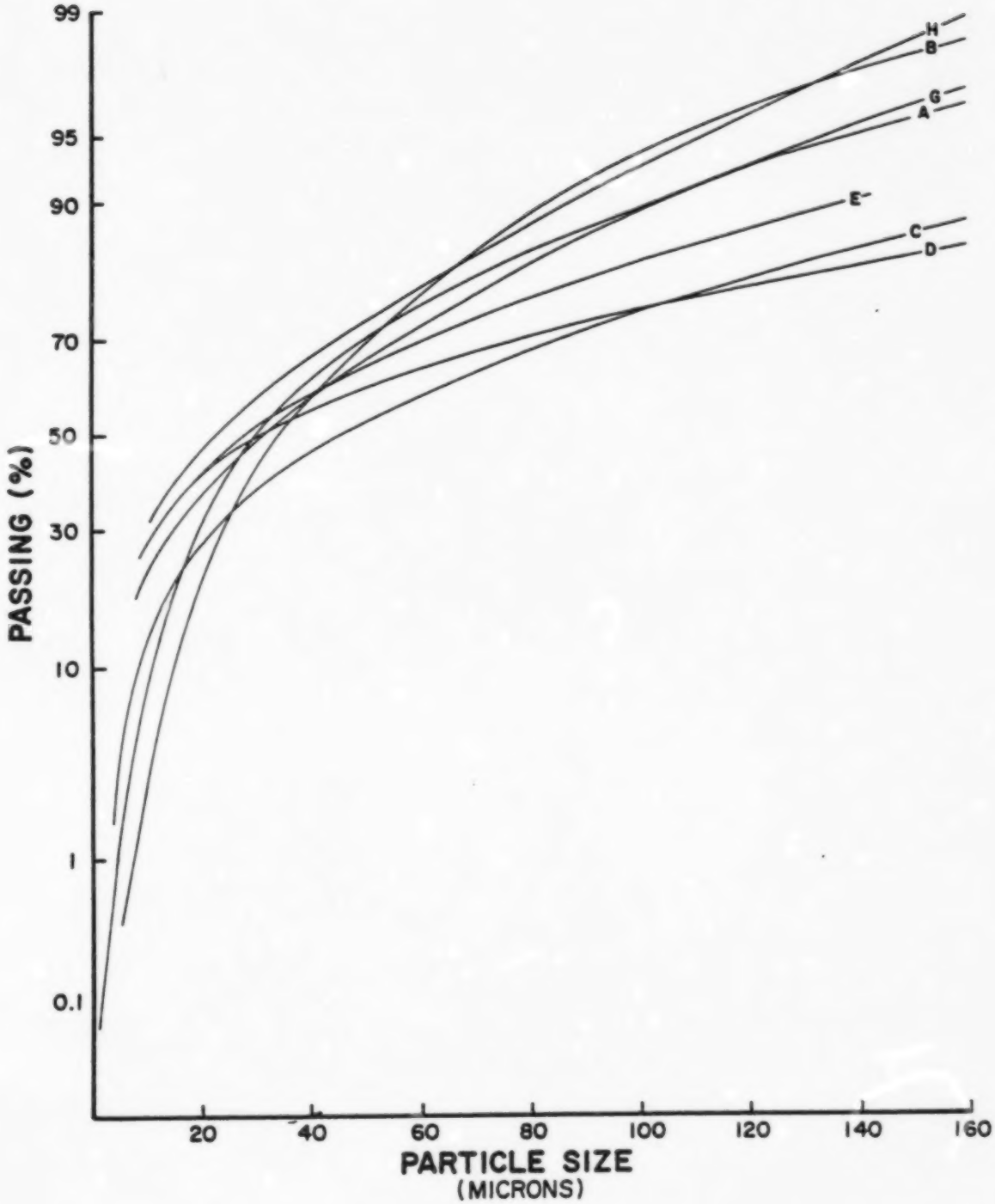

FIGURE 4.5: Antimony metal distribution for flotation feed.

TABLE 4.1

OVERALL ANTIMONY GRADE AND RECOVERY
FOR EACH TEST

		FEED GRADE (%Sb)	CONC. GRADE (%Sb)	RECOVERY (%)
TEST A	STANDARD FLOWSHEET	4.62	65.7	87.60
TEST B	STANDARD	4.82	64.1	88.20
TEST C	RO. TAIL REGRIND	4.82	64.3	89.55
TEST D	SC. CONC/CL. TAIL REGRIND	4.67	65.7	87.90
TEST E	STANDARD	4.50	65.9	88.90
TEST G	SC. CONC/CL. TAIL REGRIND	4.22	64.4	89.90
TEST H	STANDARD	3.75	64.3	88.90

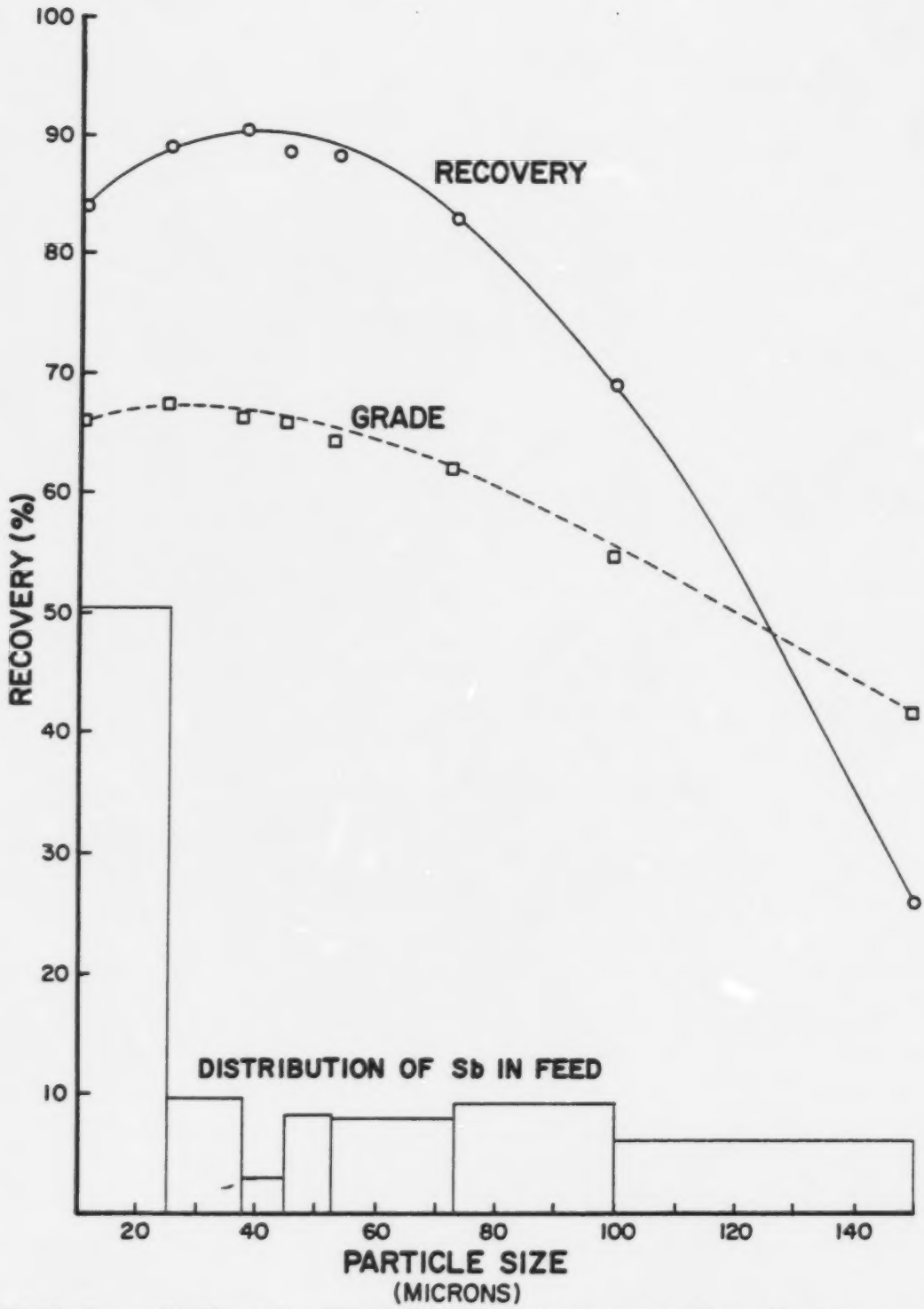

FIGURE 4.6: Grade and recovery of antimony and distribution of metal in flotation feed.

4.2 Regrind of Rougher Tails

To reduce the loss of coarse antimony in the flotation circuit, the use of a regrind on rougher tails was considered. Since a separate regrind mill was not available, the circuit was modified so that coarse material in excess of 75 microns was recycled to the primary mill. Separation of coarse material from the rougher tails was in a 10 inch cyclone, which was found to be inefficient and resulted in a high recycle tonnage to the secondary mill.

Modifications to the flowsheet by recycling solids to the secondary mill resulted in an increase of coarse antimony in the flotation circuit feed. As illustrated in Figure 4.7, the distribution of antimony particle sizes in the flotation feed shifted. However, increase in coarse material and the decrease in fines did not improve overall recovery.

4.3 Regrind of Scavenger Concentrate and Cleaner Tails

The flowsheet was revised to recycle oversize (+74 micron) material from the scavenger concentrate and cleaner tails through the grinding circuit for regrinding. The process configuration is illustrated in Figure 4.3. Scavenger concentrate and cleaner tails streams were mixed in a pump box and fed to a 10 inch cyclone for size separation. The cyclone underflow reported to the primary mill and the overflow was retreated in the secondary rougher flotation. Reagent dosages and addition points were kept the same as for previous tests.

Various process streams were sampled and analysed to determine antimony recovery by particle size. The recirculating load on the mill resulted in an increase of coarse antimony concentration in flotation feed and a decrease in the concentration of intermediate antimony particle size (25-75 microns) as illustrated in Figure 4.8. During Test D, the regrind cyclone underflow was found to contain a significant amount of fines due to the low pressure and erratic flow of the regrind cyclone feed.

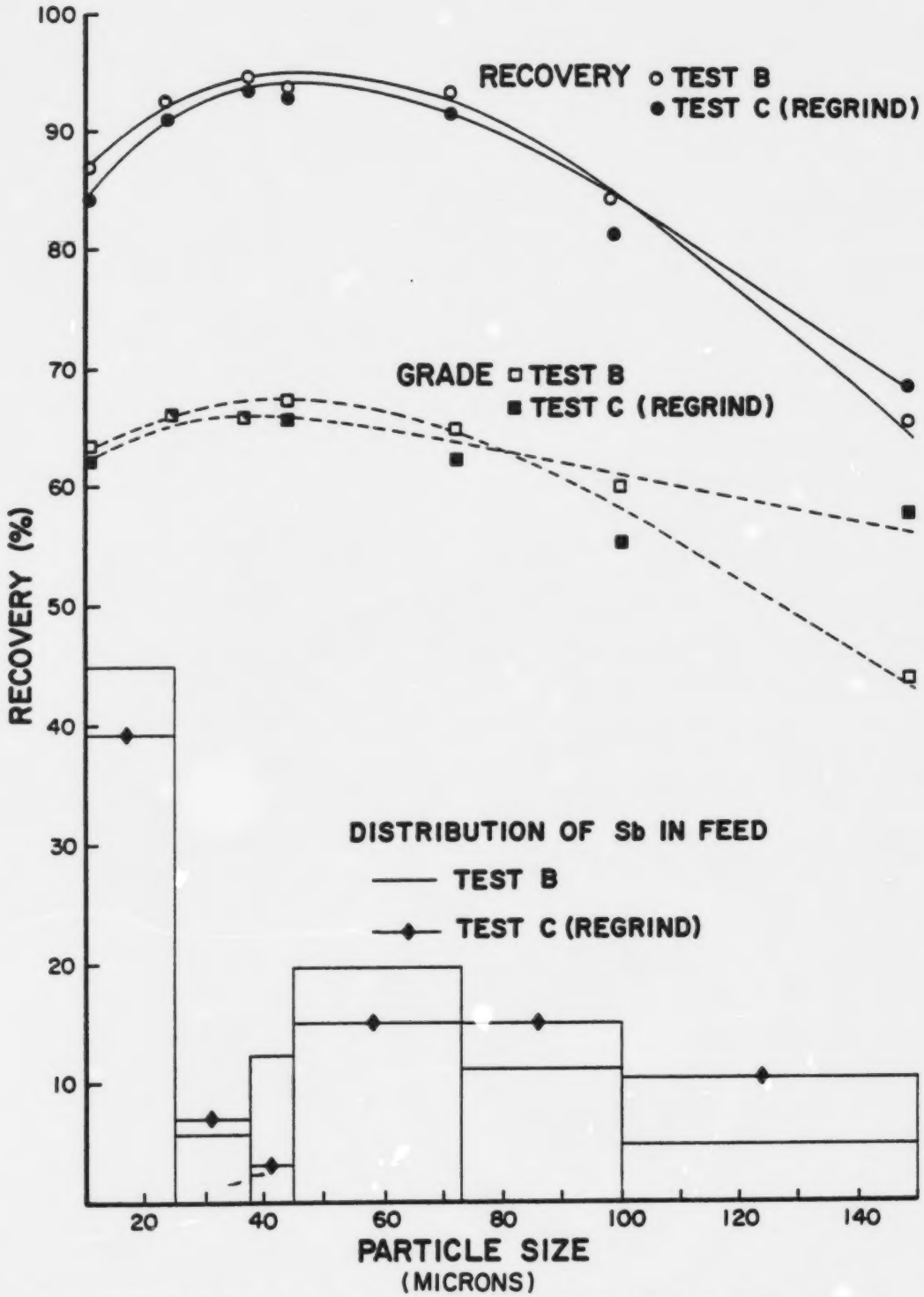

FIGURE 4.7: Grade and recovery of antimony with a regrind of rougher tails.

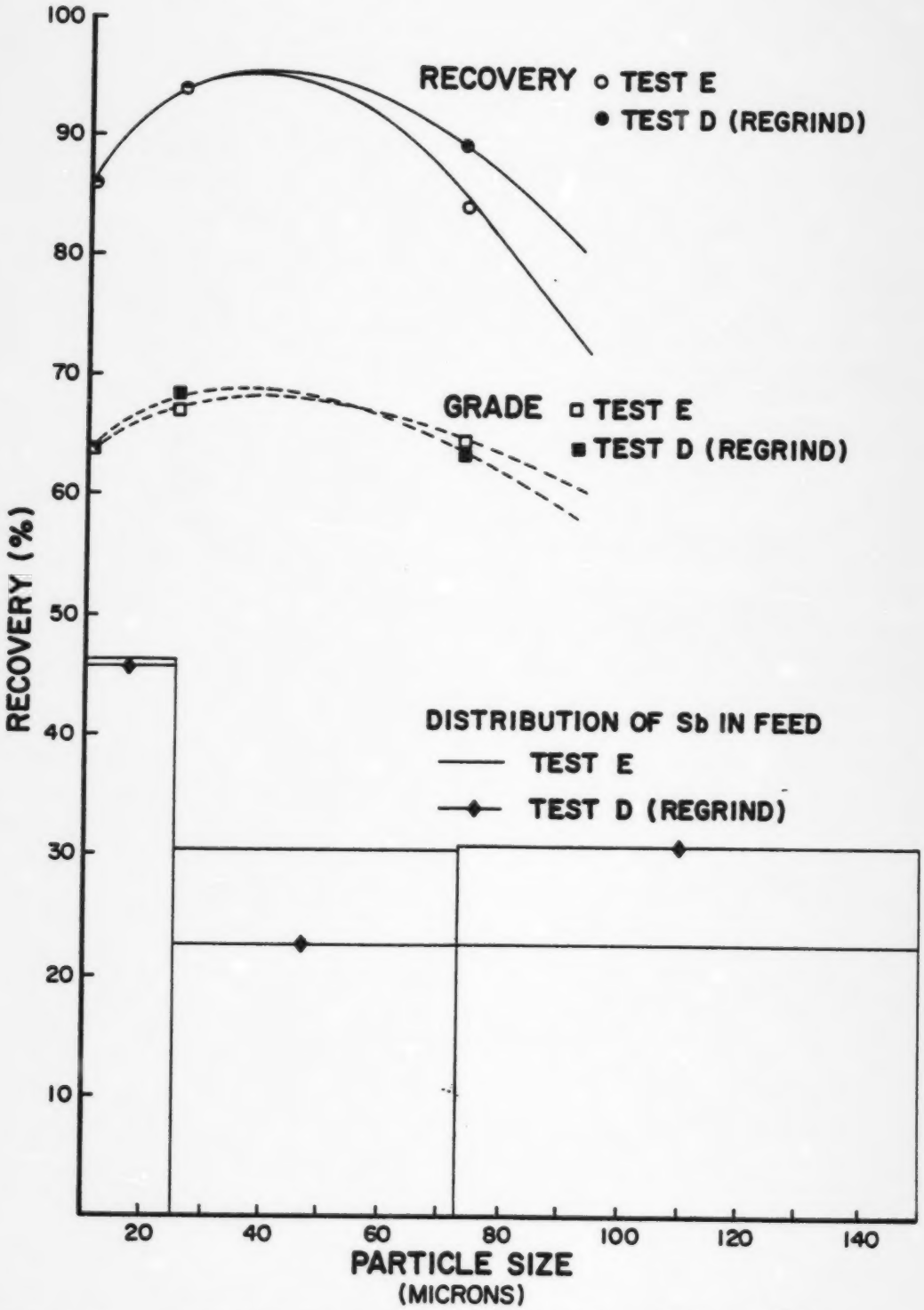

FIGURE 4.8: Overall grade and recovery of antimony with regrind of scavenger concentrate and cleaner tail.

To overcome the inefficient operation of the regrind cyclone, the impeller speed of the cyclone feed pump was increased for Test F. The efficiency of the cyclone operation was determined by sampling each cyclone stream and determining the particle size distribution as illustrated in Figure 4.9, Test F. The d_{50} (50% of feed recovery to underflow) was found to be 56 microns for the optimum operation of the 10 inch Krebs cyclone. About 25% of particles less than 25 microns were recovered in the underflow.

Subsequent to achieving an optimum particle size separation using a regrind cyclone, Tests H and G were carried out. The use of an oversize recycle to the grinding circuit increased the antimony distribution in the middle to large particle size range as illustrated in Figure 4.10. An increase in antimony content and an increase in recovery for particles greater than 75 microns may account for the overall slight improvement in recovery from 88.9% to 89.9%. It is evident that the use of a recycle on the secondary mill decreases the amount of minus 25 micron antimony with a minimal change in recovery.

4.4 Unit Operations - Mass Balance

A mass balance program was developed on a spreadsheet using a convergence technique [4]. The program was designed for a specific flowsheet and any alterations to the process flow would require reconfiguration of the program. For Tests A and H, individual mass balance programs were used to assess antimony recovery in the selected particle size ranges of various process streams. A summary of mass balance calculations for dry solids and antimony is included in Appendix I and a plot of recovery versus particle size for each unit operation is shown in Figure 4.11 and Figure 4.12.

For the standard flowsheet, the overall antimony recovery decreases for particle sizes greater than 75 microns, as shown in Figure 4.11. Similarly, the rougher and scavenger have limited recovery of coarse antimony which is probably due to liberation. Coarse particles having a substantial surface area of antimony may be recovered in a rougher circuit but lost in the cleaning stage because cleaner operating conditions are normally selected to achieve optimum grade. The

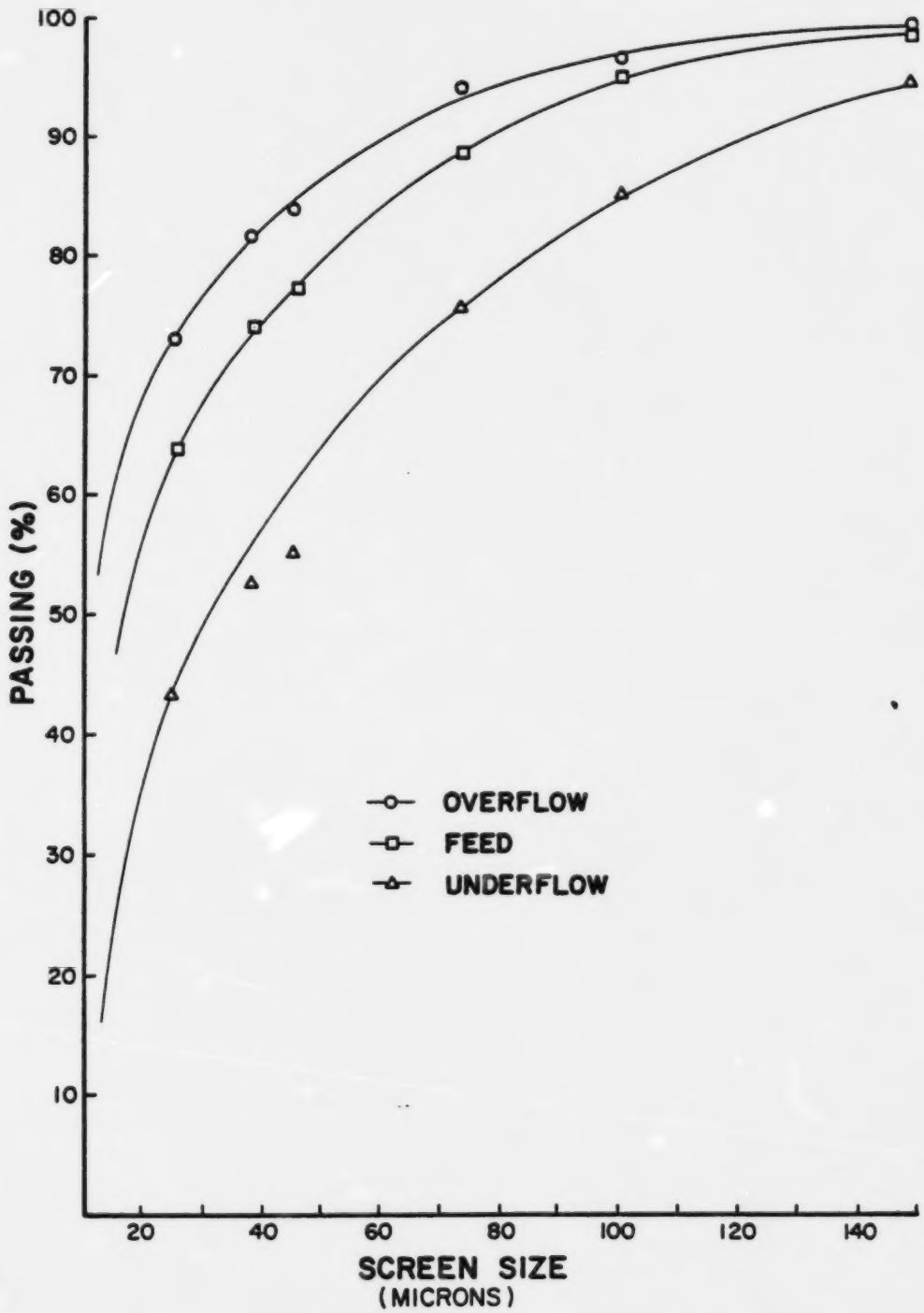

FIGURE 4.9: Particle size analysis of regrind cyclone streams for rougher tail regrind; Test F (10" cyclone).

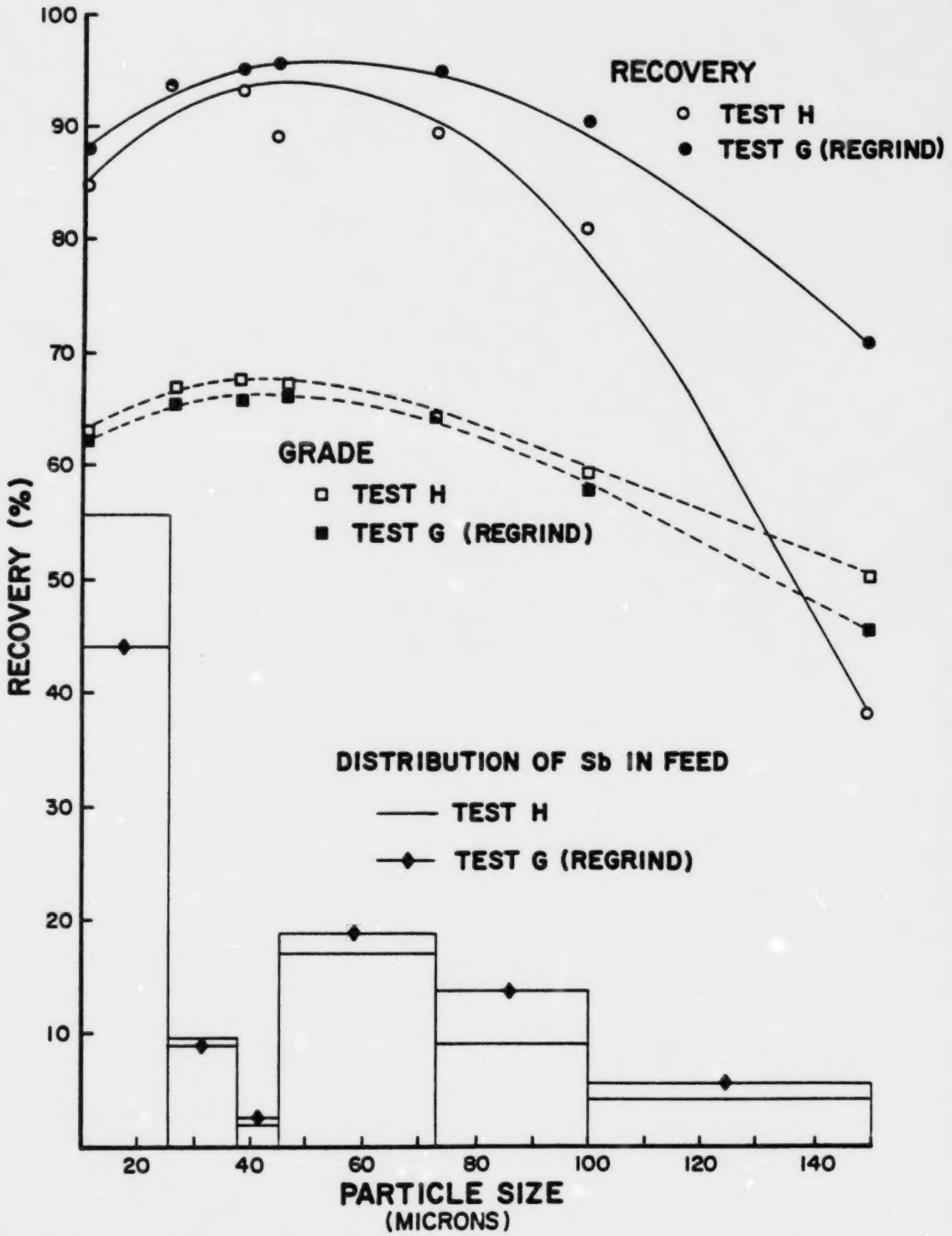

FIGURE 4.10: Grade and recovery of antimony with a regrind of scavenger concentrate and cleaner tails.

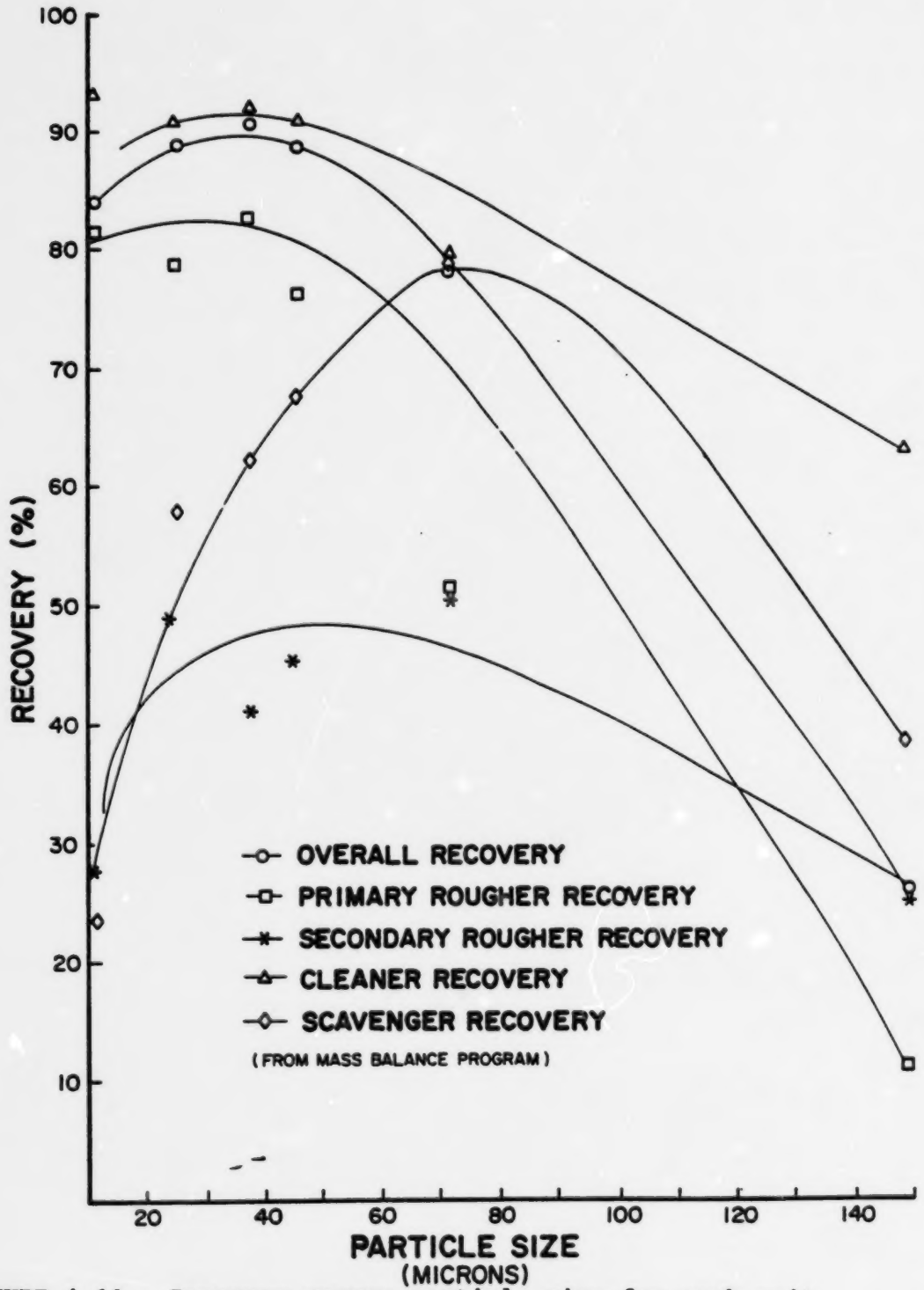

FIGURE 4.11: Recovery versus particle size for each unit operation in Test A (standard flowsheet).

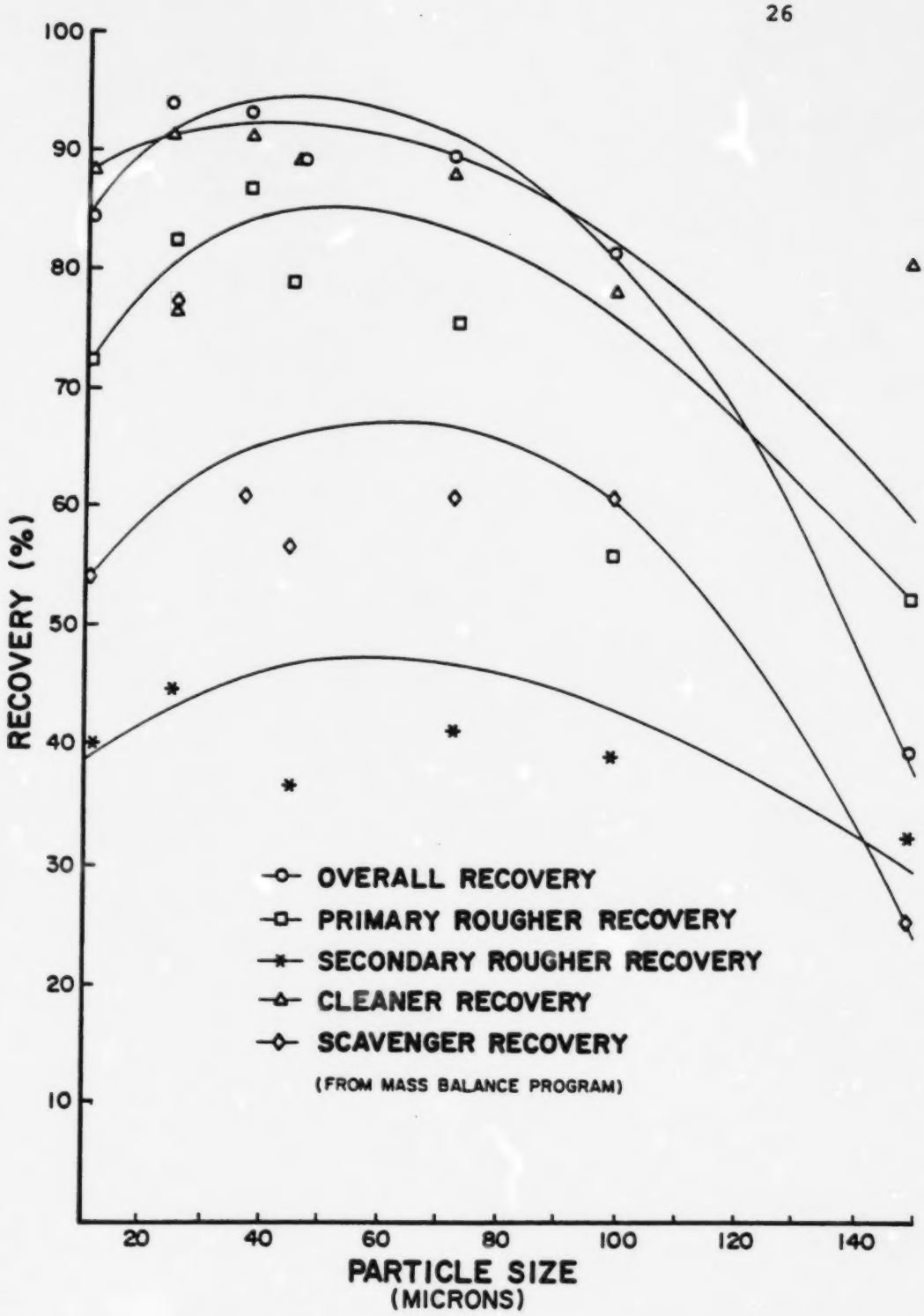

FIGURE 4.12: Recovery versus particle size for each unit operation in Test H (regrind of scavenger concentrate and cleaner tails).

antimony contained in the plus 75 micron particle size range has limited recovery for each unit operation.

In the standard flowsheet, the primary rougher particle size-recovery relationship is similar to the overall recovery of the circuit. Low antimony recoveries for the minus 40 micron particles have been observed in the secondary rougher and scavenger circuits. Essentially, most of the fine material is recovered in the primary rougher with no loss of these fines in the cleaning stages. The loss of antimony less than 40 microns in secondary roughers and scavengers may be due to residence time, reagent concentration effects and/or antimony mineralogical composition. The general shape of the antimony recovery curves, peaking in the range of 50 to 90 microns, suggests that recovery is related to particle size and liberation characteristics of the ore.

Mass balance calculations performed on scavenger concentrate/cleaner tails regrind indicate similar trends for antimony recovery versus particle size relationships in each unit operation (as illustrated in Figure 4.12). The use of a regrind flow configuration has not directly altered recovery.

4.5 Summary of Recovery Versus Particle Size Relationships

With the standard flowsheet, the optimum particle size range for recovery was determined to be in the range of 25 to 75 microns for each unit operation. For each test, a net change in the overall recovery was not observed. General plant recovery versus particle size trends are shown in Figure 4.13 for all tests. The increase in recoveries for the coarse fraction has been attributed to the net increase in coarse material concentration which was a result of recirculating loads in the grinding circuit. The limitation on recovery for antimony minerals less than 25 microns in size may not be completely attributable to particle size. Other limitations may include liberation of stibnite, non-stibnite mineralization of antimony, circuit residence time, and reagent dosages.

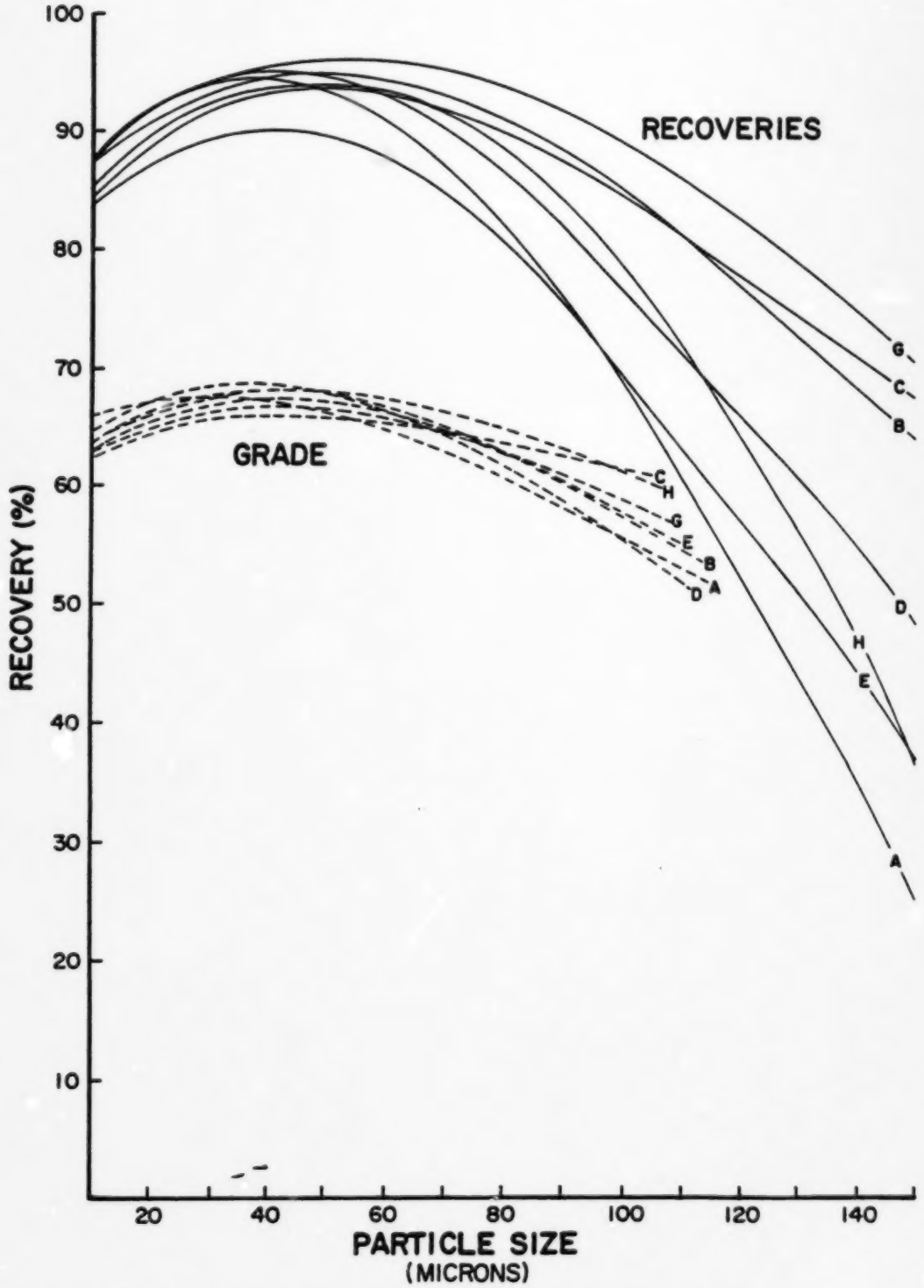

FIGURE 4.13: Grade and recovery versus particle size relationships for each plant test.

4.6 Mineralogy of Major Process Streams

To assist in identifying reasons for antimony loss, samples of scavenger tails, cleaner concentrate and plant feed were taken on Tests G and H for mineralogical identification and quantification of mineral liberation. Antimony particle size distribution data and plant recovery by particle size has indicated three distinct zones of recovery variation. Therefore, the composite samples were sized at 25 and 75 micron intervals to determine variation of mineral composition in each particle size range and possible recovery limitations.

The antimony bearing phases of stibnite (Sb_2S_3), berthierite ($FeSb_2S_4$), gudmundite (FeSbS), and native antimony (Sb^o) are present in all samples. Mineralogy was done by the Research and Productivity Council [5] using EPXM (electron probe x-ray microanalysis) techniques. Iron composition was found to vary in association with stibnite minerals. Stibnite containing iron less than 27% (wt%) was identified as iron-stibnite, which is a separate species from berthierite and gudmundite. A distribution of antimony minerals is summarized in Table 4.2 and graphically represented in Figures 4.14 and 4.15 for Tests H and G respectively.

Stibnite is substantially liberated (mineral liberation is defined as 90% of surface area of the mineral being exposed) relative to other antimony minerals in the ground ore, except in the coarse, or +75 micron, fraction. Most of the liberated grains of stibnite range from 2 to 170 microns and more than half of the liberated stibnite ranges from 2 to 45 microns. Each size range of the scavenger tails contains significant amounts of iron-rich stibnite or non-liberated stibnite. The following observations are based on the mineralogical assessment of the major process streams. Eight hour composite sampling does not reflect possible variations in ore composition.

- In the coarse fraction (+75 microns), the regrind flowsheet configuration has reduced the liberation of antimony from 84.9% to 55.3% which does not explain the net improvement in recovery of antimony, but does account for a lower grade (see Figure 4.10). It is interesting to note the difference in the iron-stibnite distribution for coarse antimony with regrind. When the liberation of stibnite is low (as shown in Figure 4.14 to be 0.6%), the distribution of iron-stibnite is low and as the liberation increases to 60% (as

TABLE 4.2

DISTRIBUTION OF MINERALS IN MAJOR PROCESS STREAMS FOR
TEST H (STANDARD FLOWSHEET) AND
TEST G (REGRIND OF SCAVENGER CONCENTRATE AND CLEANER TAILS)

RPC NO.	TEST NO.	PARTICLE SIZE	DISTRIBUTION OF MINERALS			
			NAT. ANTIMONY	STIBNITE	FE-STIBNITE	BERTHIERITE
6631	H-Tail	+75	1.35	93.20	4.05	1.35
6632	H-Tail	+25	0.04	78.10	21.90	0.27
6633	H-Tail	-25	1.39	48.61	50.00	1.39
6634	H-Feed	+75	0.78	69.77	29.07	0.39
6635	H-Feed	+25	0.73	97.90	1.40	0.00
6636	H-Feed	-25	0.00	98.30	1.64	0.09
6637	H-Conc	+75	1.47	95.39	3.15	0.00
6638	H-Conc	+25	0.18	98.20	1.57	0.00
6639	H-Conc	-25	1.89	94.60	3.50	0.00
6622	G-Tail	+75	38.10	0.72	52.60	8.64
6623	G-Tail	+25	7.62	91.30	0.00	1.09
6624	G-Tail	-25	0.00	15.90	82.50	3.17
6625	G-Feed	+75	4.98	94.60	0.45	0.00
6626	G-Feed	+25	4.04	87.40	8.40	0.19
6627	G-Feed	-25	1.00	85.30	14.70	0.00
6628	G-Conc	+75	0.68	97.10	2.22	0.05
6629	G-Conc	+25	4.71	92.20	3.10	0.00
6630	G-Conc	-25	2.66	94.32	3.01	0.00

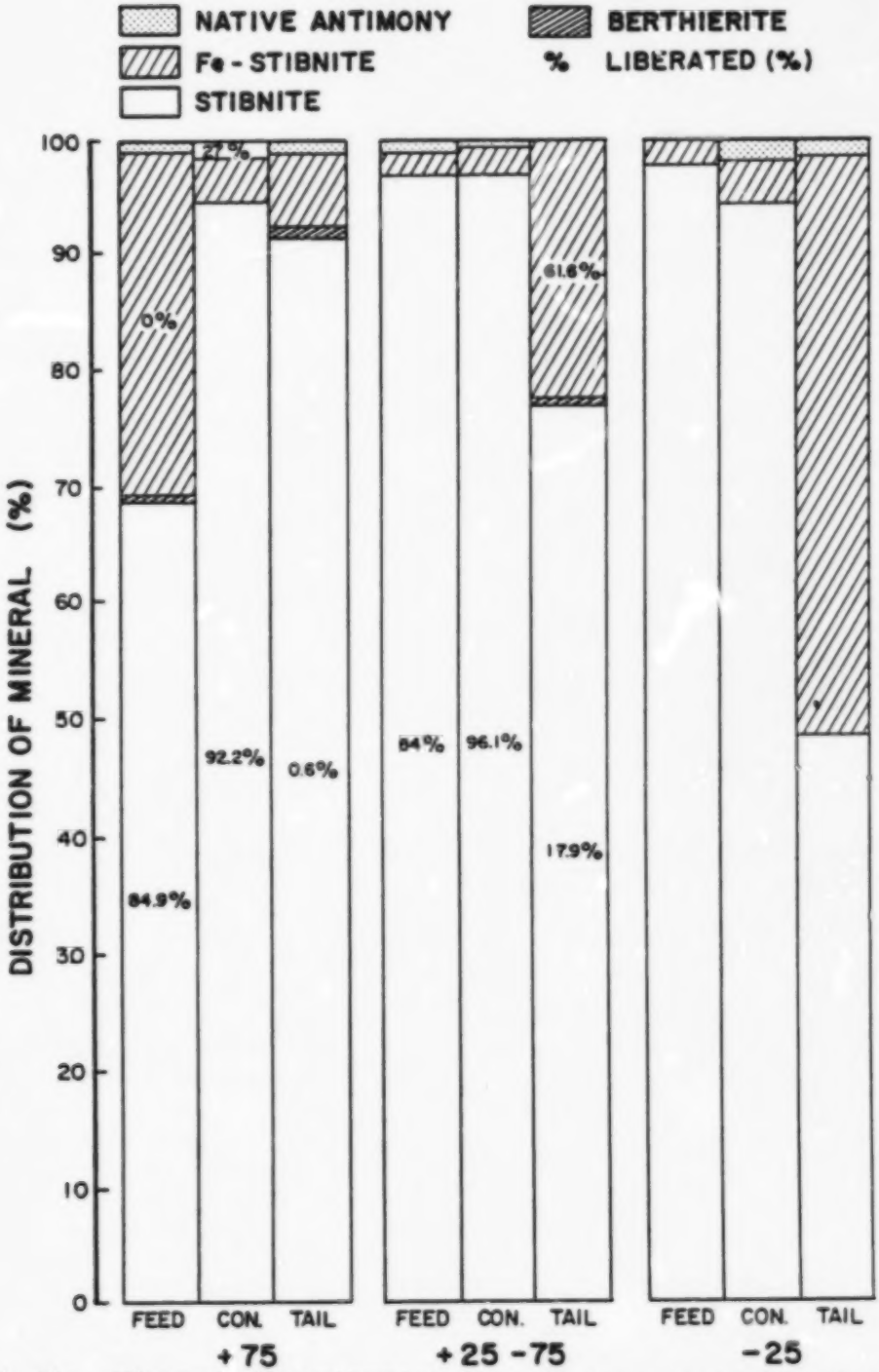

FIGURE 4.14: Mineral distribution for various particle size ranges on feed, concentrate and tails for Test H (standard flowsheet) [Ref. 4]

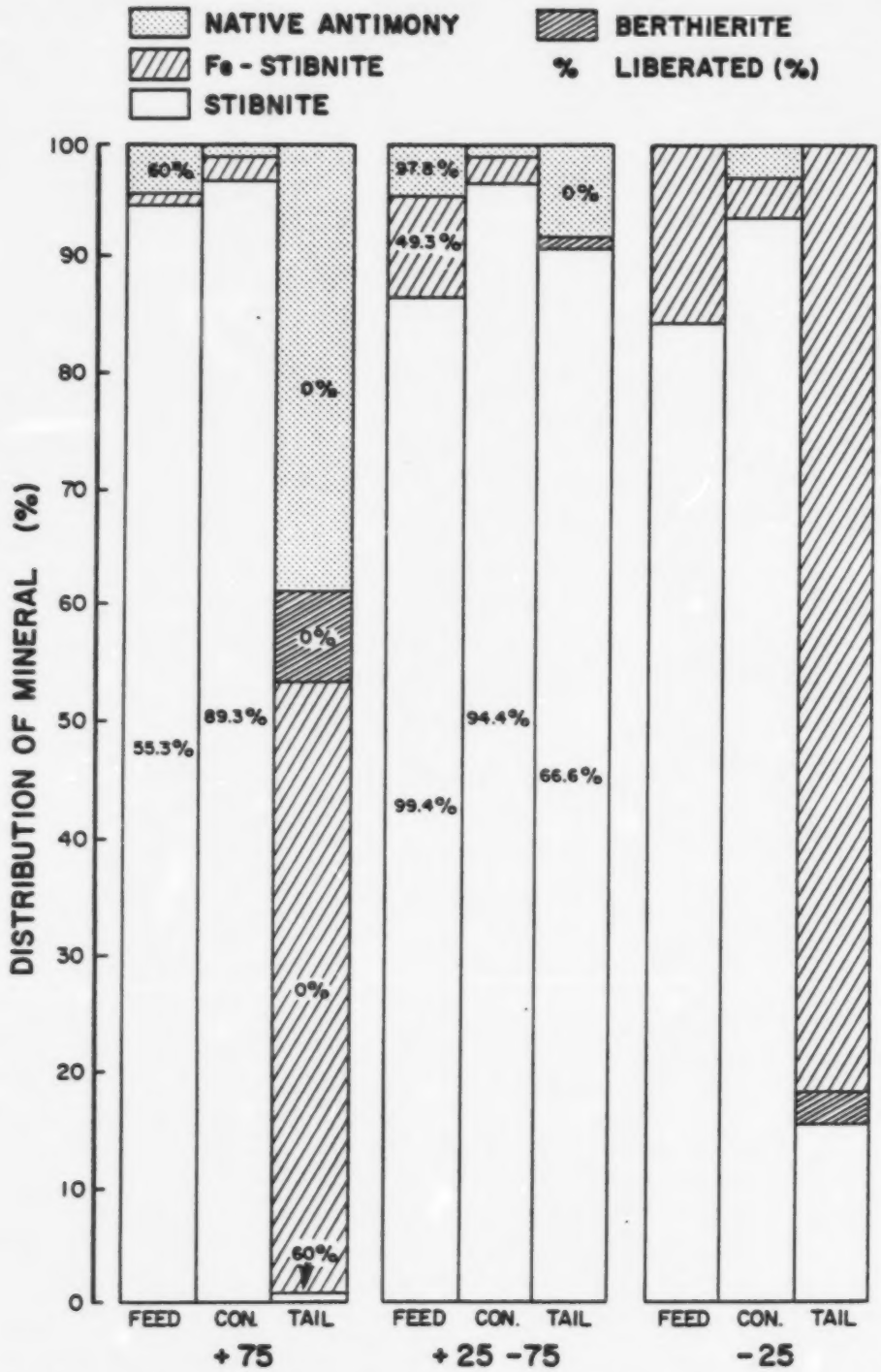

FIGURE 4.15: Mineral distribution for various particle size ranges on feed, concentrate and tails for Test G (regrind of scavenger concentrate and cleaner tails) [Ref. 5]

shown in Figure 4.15), the distribution of iron-stibnite increases. The low recovery of iron-stibnite minerals in the regrind flowsheet may be a result of a change in grinding characteristics.

- The regrind improved the liberation characteristics of stibnite in the 25 to 75 micron fraction from 84% to 99.4%. The loss of antimony in this fraction is predominantly due to stibnite having a liberation of 66.6%. This data suggests that a significant portion of recoverable stibnite must be ground to less than 25 microns to achieve a liberation that is suitable for flotation.

- Liberation data for particles less than 25 microns is not available and the tails contain minor levels of iron-rich stibnite. For the regrind circuit, the levels of iron-rich stibnite have increased in the feed which is possibly due to a shift in grind.

Subsequent mineralogical investigative studies were done by Wittech Development Inc. [6] on samples of feed, concentrate and tails for Test E. The study's objective was to assess process optimization parameters based on mineral composition of major processing streams and to determine possible variations in ore composition. A summary of the study's results are graphically presented in Figure 4.16. Mineralogy similar to that by R.P.C. was observed with the addition of tetrahedrite ($Cu_{12}Sb_4S_{13}$). The presence of tetrahedrite may be random in mill feed.

Liberation data for the standard flowsheet was found to coincide to particle size recovery trends (as indicated by Test H). An optimum liberation of stibnite was determined to be in the range of 37 to 53 microns, thereby agreeing with recovery-particle size relationships determined by the assessment of plant separation efficiency. In the fine fraction, several examples of stibnite were found to be coated either by silicate or oxide minerals, which was attributed as a recovery limitation.

The particle size analysis data and the mineralogical data does not clearly indicate a reason for a suppressed recovery in the minus 25 micron fraction. Based on the mineral distribution data in each size fraction, stibnite recoveries have been calculated to be around 95% for particles under 75 microns. A limited stibnite recovery in the coarse fraction has been attributed to poor liberation. The loss of stibnite in the fine fraction may be a combination of liberation, flotation

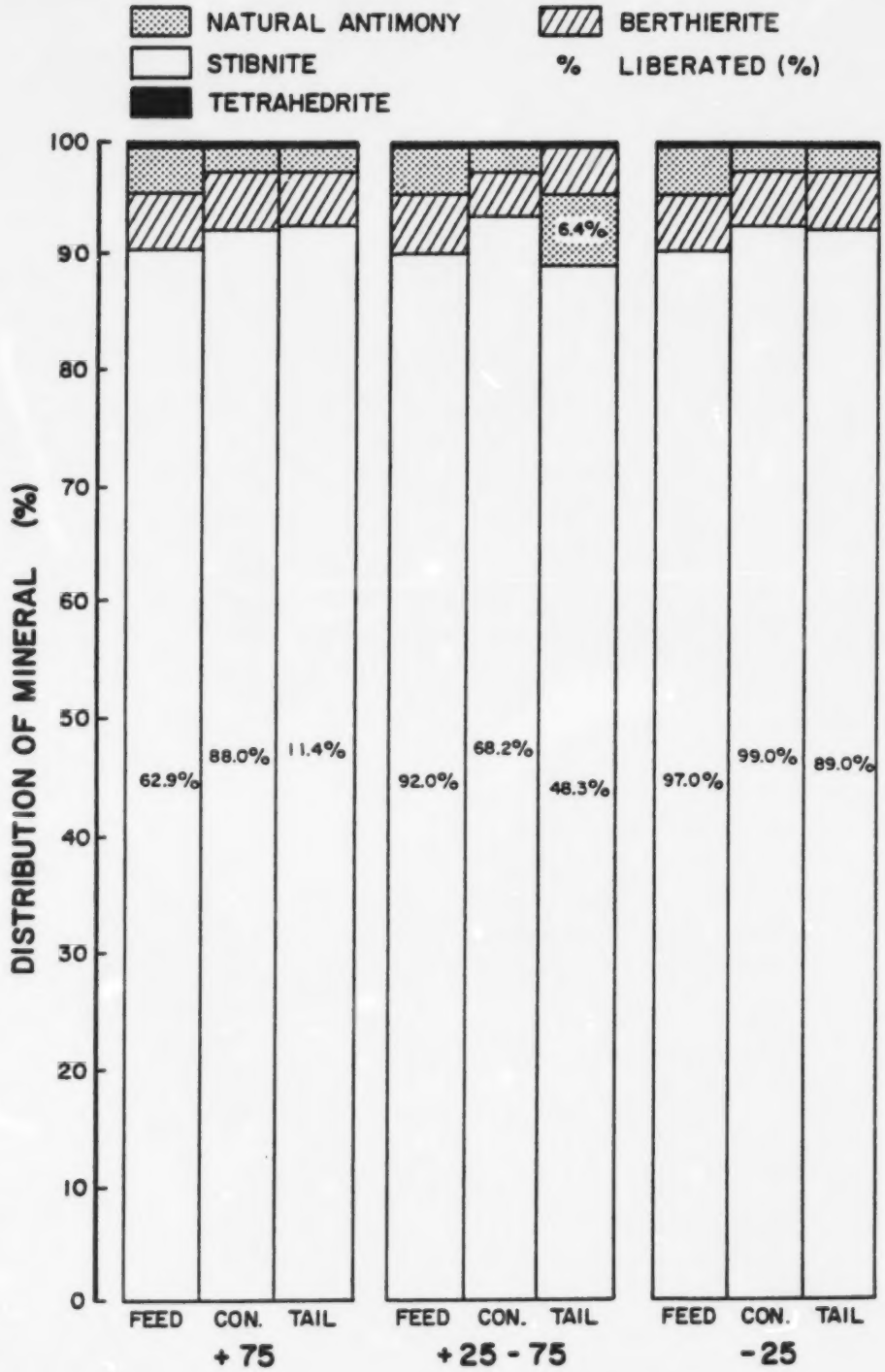

FIGURE 4.16: Mineral Distribution for various particle size ranges on feed, concentrate and tails for Test E (standard flowsheet) [Ref. 6].

kinetics and/or reagent dosage. Separation data on the non-stibnite antimony minerals has been inconsistent and may be due to the limited selectivity in the flotation of iron-stibnite, berthierite, and gudmundite.

5.0 CONCLUSIONS

Prior to this study, it had been accepted that the loss of metal at the Durham Concentrator was due to overgrinding. The study's objective was to quantify the problems associated with grade and recovery. The methodology used in this study provides the technical operating staff with a standard procedure for assessing the efficiency of the concentrator. In essence, the mill has been operating at optimum efficiency considering the technical complexity grade recovery limitations.

There was no evidence of improvement in overall circuit performance which could be credited to variations in flowsheet configuration or the use of coarse recirculation to the grinding circuit. Analysis of the incremental recovery for each particle size range suggests that the recirculating load on the secondary mill increased the relative amount of antimony in the plus 75 micron fraction by about 38% and the relative recovery by about 6%. The decrease of antimony content in the minus 75 micron fraction did not affect the recovery for this particle size range, nor did it change the overall recovery of the concentrator. Having more (+ 75 micron) material resulted in an overall lower grade but this relationship did not hold true for other particle size ranges. An optimum grade-recovery relationship was found in the 25 to 75 micron range.

The complexity of grade-recovery relationships is affected by the complex mineralogy of the various antimony bearing minerals. Liberation and the iron-antimony mineral phases have been identified as ore characteristics that limit total metal recovery. Additional studies would be required to assess the presence of liberated stibnite in tailings.

Based on the liberation study, the results of using a regrind in attempts to recover coarse antimony are inconclusive. One may still find a portion of the antimony which is not liberated even with the primary grind optimized to produce a 25 to 75 micron product. However, the use of a regrind would be preferred to primary overgrinding of the ore to resolve liberation problems.

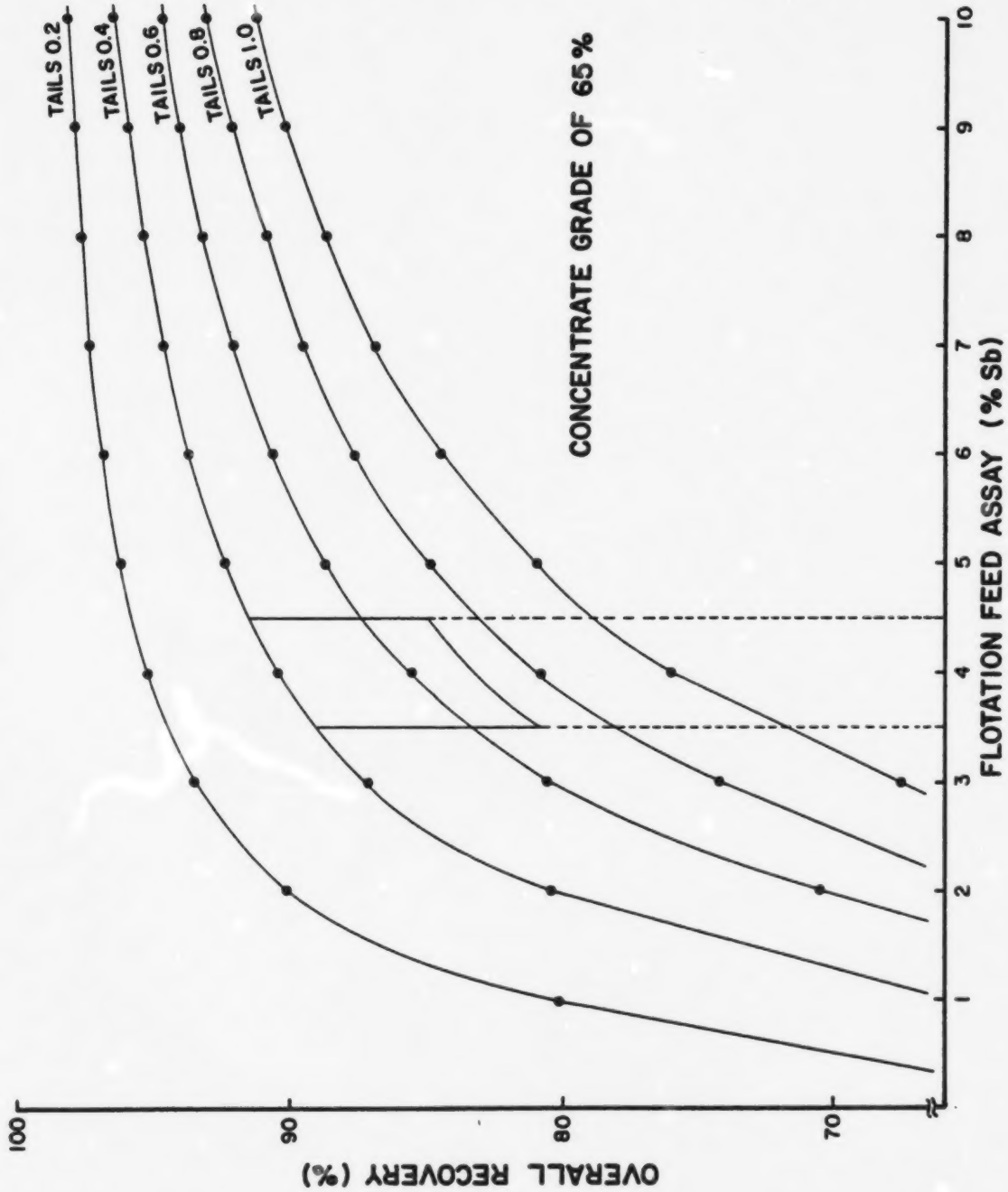

FIGURE 5.1 Antimony recovery as a function of feed and tail assays.

As demonstrated by the bench-scale grinding-flotation tests and separation tests on secondary grind cyclone underflow, overgrinding the ore and inadequate classification in the grinding circuit can result in grade-recovery limitations. Overgrinding will increase the concentration of particles less than 25 microns and processing limitations may result in reagent dosage and/or flotation kinetics. Optimum conditions for a revised flowsheet have not been identified in this test program. Based on this preliminary study, an optimum flowsheet should include the following features:

A. A primary grinding circuit capable of reducing crushed ore to a particle size less than 75 micron.

B. Classification in the primary grind should include some means of removing recoverable-high grade antimony.

C. A separate regrind mill for antimony middling that may range from submicron material to 50-75 microns.

D. A separate flotation circuit for slow floating antimony which may include non-stibnite antimony minerals.

In addition to potential flowsheet modifications, control of flotation feed and tail grades also has a direct influence on the overall recovery of the flotation circuit. The relationship between feed grade, tail grade and overall plant recovery is illustrated in Figure 5.1. For a concentrate grade of 65%, maintaining the plant at an average recovery of 88.5% (average of all plant trials) requires an integrated control on final tails ranging from 0.40% to 0.55% Sb with respective feed grades of 3.5% to 4.5% Sb.

Given a constant throughput of mill tonnage, slight variations in feed grade have a stronger impact on economic returns than do recovery variances. Revenues can increase by about 28% for a feed grade change from 3.5% to 4.5% Sb and only about 1.7% for an increase in recovery from 88.5% to 90%. A variation in grade and recovery with the value of ore is illustrated in Figure 5.2. Based on October, 1986 concentrate market value (U.S. $20/MTU), the value of the ore can range from approximately U.S. $103.25/mt to U.S. $132.75/mt, for a respective variation

in head grade from 3.5% to 4.5% Sb at 88.5% recovery. Increasing the recovery to 90% increases the value of the ore from approximately U.S. $105.00/mt to U.S. $135.00/mt for the same head grade variations. Improvements in antimony recovery by 1.7% would result in net increases in annual revenues by U.S. $189,000 (CDN $223,000) to U.S. $243,000 (CDN $287,000) based on an annual throughput of 108,000 mt of ore and feed grades from 3.5% to 4.5% Sb respectively.

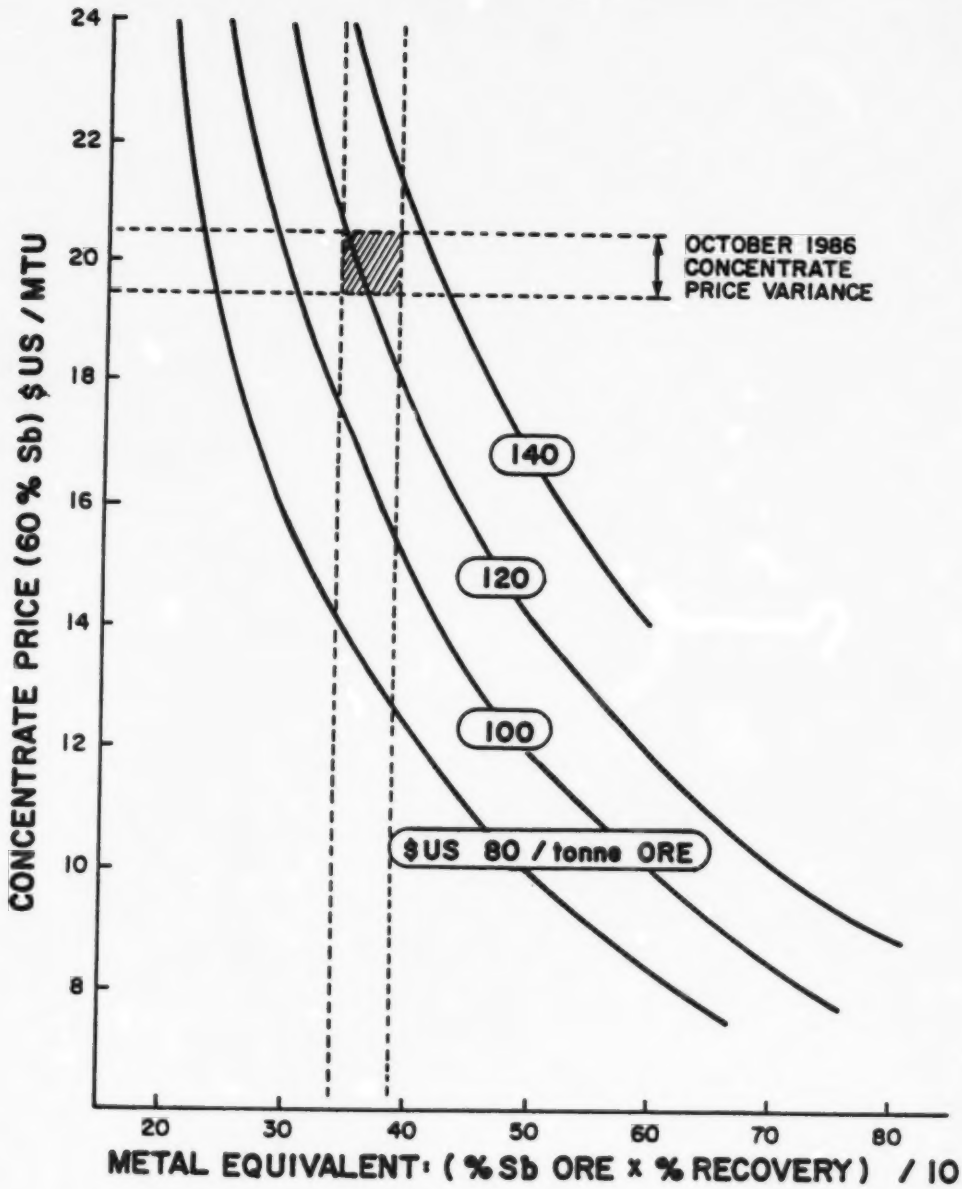

FIGURE 5.2: Value of ore versus production of metal content.

6.0 RECOMMENDATIONS

An understanding of antimony recovery limitations has provided a direction for further development. Quantitative assessment of recovery limitations has illustrated that a selective particle size range for optimum recovery is required. To achieve an optimum overall recovery, the circuit must be designed and operated to prevent excessive generation of fines. It is therefore recommended that grinding and separation be integrated, to ensure optimum recovery on the wide range of antimony grain sizes.

The recovery limitations discussed in this report have led to the conceptual design of an integrated flowsheet. The integration of staged grinding and flotation, as illustrated in Figure 6.1, has been proposed to overcome processing problems due to the diverse grain sizes and particle size flotation kinetics. The revised flowsheet configuration includes flash flotation, open circuit configuration for primary rougher flotation, staged grinding, staged reagent addition-conditioning, and an extended residence time flotation circuit. It is recommended that further development include test programs that will elaborate on the concepts of the proposed integrated flowsheet.

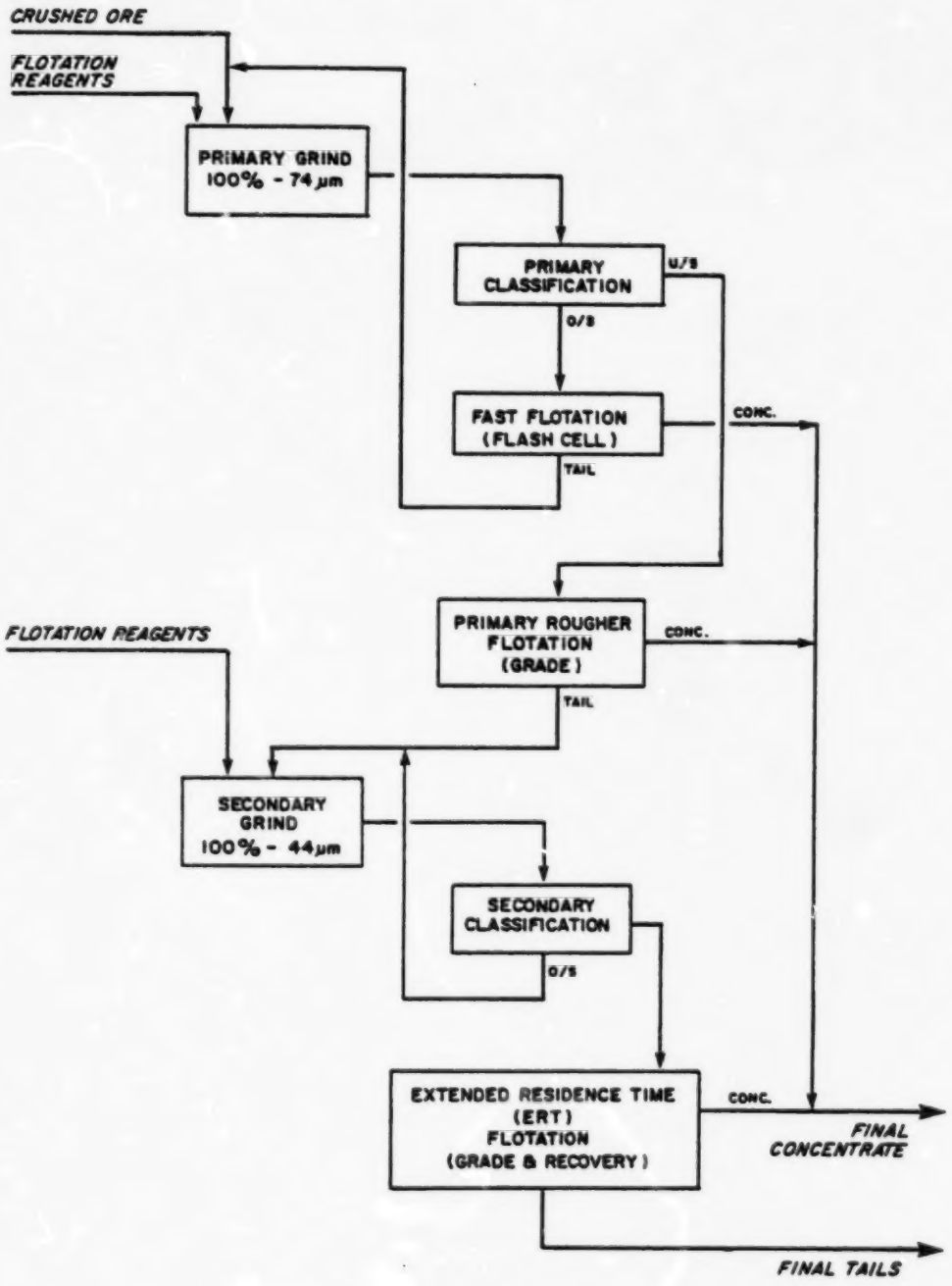

FIGURE 6.1: Conceptual flowsheet based on recovery limitations.

7.0 REFERENCES

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5. MELLUISH, J., Mineralogical Investigations of Antimony Samples. Report Nos. M/86/018 and M/86/020, Research and Productivity Council, 1986.

6. DAVISON, J.G., Mineralogy of Metallurgical Products from Lake George Antimony Mine. Wittech Development Inc., Department of Natural Resources and Energy, Open File Report 88-22, 1987.

APPENDIX I

Spreadsheet Mass Balance Calculations

Abbreviations for Process Streams	
ROF:	Rougher Feed
SRF:	Secondary Rougher Feed
CF:	Cleaner Feed
SF:	Scavenger Feed
ROC:	Rougher Concentrate
SRC:	Secondary Rougher Feed
CC:	Cleaner Concentrate
SC:	Scavenger Concentrate
ROT:	Rougher Tails
SRT:	Secondary Rougher Tails
CT:	Cleaner Tails
ST:	Scavenger Tails

Overall Mass Balance for Test A, Standard Flowsheet, 0-200 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 20.00 , Overall flowsheet recovery = 80.10

Assays (%Sb):	ROF =	4.02	ROC =	45.30	ROT =	1.02
	(SRF)=	1.04	SRC =	29.70	SRT =	1.06
	CF =	39.30	CC =	64.10	CT =	9.21
	(SF) =	1.44	SC =	14.10	ST =	0.61

Initial Guess for recycle SC (mt) = 10.00

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	4.02	45.30	1.02	5.64	29.70	1.06	39.30	64.10	9.21	2.46	14.10	0.61
Sb TONNAGE	0.96	0.78	0.19	1.60	1.34	0.25	2.45	0.85	0.45	0.70	0.55	0.11
TONNAGE	20.00	1.72	18.28	28.28	4.53	23.76	6.24	1.33	4.92	28.67	3.93	18.67
RECOVERY (%)		80.65			84.23			89.41			78.58	
Iterative Calculation Results												
ASSAY	4.02	45.30	1.02	1.04	29.70	1.06	39.30	64.10	9.21	1.44	14.10	0.61
Sb TONNAGE	0.96	0.78	0.19	0.36	0.16	0.20	0.80	0.85	0.00	0.29	0.17	0.11
TONNAGE	20.00	1.72	18.28	19.50	0.53	18.97	2.25	1.33	0.92	19.89	1.22	18.67
wt% of ROF	100.00	8.58	91.42	97.51	2.65	94.87	11.23	6.63	4.60	99.47	6.10	93.37
RECOVERY (%)		80.65			43.89			89.41			60.15	

Overall Mass Balance for Test A, Standard Flowsheet, +149 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 4.56 , Overall flowsheet recovery = 26.57

Assays (%Sb):	ROF =	0.57	ROC =	19.00	ROT =	0.49
	(SRF)=	0.75	SRC =	27.10	SRT =	0.56
	CF =	26.50	CC =	43.00	CT =	15.70
	(SF) =	0.60	SC =	23.90	ST =	0.42

Initial Guess for recycle SC (mt) = 10.00

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	0.57	19.00	0.49	16.59	27.10	0.56	26.50	43.00	15.70	9.71	23.90	0.42
Sb TONNAGE	0.03	0.00	0.02	2.41	2.38	0.03	2.33	0.01	1.30	1.41	1.37	0.02
TONNAGE	4.56	0.02	4.54	14.54	8.78	5.76	8.80	0.02	0.79	14.54	5.75	4.54
RECOVERY (%)		14.41			98.66			63.53			97.30	
Iterative Calculation Results												
ASSAY	0.57	19.00	0.49	0.75	27.10	0.56	26.50	43.00	15.70	0.60	23.90	0.42
Sb TONNAGE	0.03	0.00	0.02	0.03	0.01	0.03	0.01	0.01	0.01	0.03	0.01	0.02
TONNAGE	4.56	0.02	4.54	4.59	0.03	4.56	0.05	0.02	0.04	4.60	0.05	4.54
wt% of ROF	100.00	0.43	99.57	100.69	0.73	99.97	1.16	0.35	0.01	100.70	1.13	99.65
RECOVERY (%)		14.41			26.04			63.53			39.12	

Overall Mass Balance for Test A, Standard Flowsheet, 75-150 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 4.78 , Overall flowsheet recovery = 77.84

Assays (%Sb):	ROF =	1.68	ROC =	59.88	ROT =	0.85
	(SRF)=	2.12	SRC =	32.98	SRT =	1.06
	CF =	47.48	CC =	63.98	CT =	23.78
	(SF) =	1.68	SC =	25.88	ST =	0.38

Initial Guess for recycle SC (mt) = 18.88

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	1.68	59.88	0.85	17.01	32.98	1.06	47.48	63.98	23.78	12.95	25.88	0.38
Sb TONNAGE	0.08	0.04	0.04	2.62	2.55	0.07	3.78	0.06	1.83	1.98	1.87	0.02
TONNAGE	4.78	0.07	4.71	14.71	7.74	6.97	7.81	0.10	7.71	14.68	7.26	4.68
RECOVERY (%)		58.13			97.10			79.48			98.52	
Iterative Calculation Results												
ASSAY	1.68	59.88	0.85	2.12	32.98	1.06	47.48	63.98	23.78	1.68	25.88	0.38
Sb TONNAGE	0.08	0.04	0.04	0.11	0.05	0.05	0.11	0.06	0.03	0.08	0.07	0.02
TONNAGE	4.78	0.07	4.71	4.96	0.17	4.80	0.23	0.10	0.14	4.94	0.25	4.68
wt% of ROF	100.00	1.43	98.57	103.87	3.47	100.40	4.85	2.05	2.85	103.25	5.30	97.95
RECOVERY (%)		58.13			51.73			79.48			78.68	

Overall Mass Balance for Test A, Standard Flowsheet, 44-75 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 2.88 , Overall flowsheet recovery = 88.45

Assays (%Sb)						
	ROF =	4.48	ROC =	57.68	ROT =	1.89
	(SRF)=	2.13	SRC =	35.88	SRT =	1.19
	CF =	51.78	CC =	66.28	CT =	16.38
	(SF) =	1.61	SC =	23.48	ST =	8.54

Initial Guess for recycle SC (mt) = 18.88

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	18	18+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	4.48	57.68	1.89	18.75	35.88	1.19	51.78	66.28	16.38	9.84	23.48	8.54
Sb TONNAGE	8.12	8.89	8.83	2.37	2.38	8.87	3.48	8.11	1.87	1.14	1.18	8.81
TONNAGE	2.88	8.16	2.64	12.64	6.56	6.87	6.73	8.16	6.56	12.64	4.78	2.64
RECOVERY (%)		76.68			96.95			98.84			96.24	
Iterative Calculation Results												
ASSAY	4.48	57.68	1.89	2.13	35.88	1.19	51.78	66.28	16.38	1.61	23.48	8.54
Sb TONNAGE	8.12	8.89	8.83	8.86	8.83	8.83	8.12	8.11	8.81	8.84	8.83	8.81
TONNAGE	2.88	8.16	2.64	2.77	8.88	2.69	8.24	8.16	8.88	2.76	8.13	2.64
wt% of ROF	188.88	5.86	94.14	98.75	2.75	96.88	8.61	5.88	2.73	98.73	4.61	94.12
RECOVERY (%)		76.68			45.73			98.84			67.98	

Overall Mass Balance for Test A, Standard Flowsheet, 37-44 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 0.42 , Overall flowsheet recovery = 98.35

Assays (%Sb):	ROF =	5.82	ROC =	56.20	ROT =	1.11
	(SRF)=	2.05	SRC =	36.70	SRT =	1.24
	CF =	50.00	CC =	66.40	CT =	12.30
	(SF) =	1.56	SC =	22.10	ST =	0.61

Initial Guess for recycle SC (mt) = 10.00

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	5.82	56.20	1.11	21.32	36.70	1.24	50.00	66.40	12.30	7.51	22.10	0.61
Sb TONNAGE	0.02	0.02	0.00	2.21	2.16	0.06	2.96	0.02	0.72	0.78	0.74	0.00
TONNAGE	0.42	0.04	0.38	10.38	5.88	4.50	5.92	0.03	5.88	10.39	3.33	0.39
RECOVERY (%)		82.56			97.48			92.54			94.48	
Iterative Calculation Results												
ASSAY	5.82	56.20	1.11	2.05	36.70	1.24	50.00	66.40	12.30	1.56	22.10	0.61
Sb TONNAGE	0.02	0.02	0.00	0.01	0.00	0.00	0.02	0.02	0.00	0.01	0.00	0.00
TONNAGE	0.42	0.04	0.38	0.48	0.01	0.39	0.05	0.03	0.01	0.48	0.02	0.39
wt% of ROF	100.00	8.55	91.45	95.72	2.10	93.54	10.73	7.92	2.01	96.35	4.27	92.08
RECOVERY (%)		82.56			40.78			92.54			62.68	

Overall Mass Balance for Test A, Standard Flowsheet, 25-37 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 1.42 , Overall flowsheet recovery = 89.18

Assays (%Sb):	ROF =	5.85	ROC =	48.88	ROT =	1.16
	(SRF)=	1.86	SRC =	31.58	SRT =	0.97
	CF =	41.18	CC =	67.58	CT =	0.52
	(SF) =	1.31	SC =	12.18	ST =	0.59

Initial Guess for recycle SC (mt) = 10.00

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	5.85	48.88	1.16	10.84	31.58	0.97	41.18	67.58	0.52	3.42	12.18	0.59
Sb TONNAGE	0.07	0.06	0.02	1.23	1.15	0.07	1.55	0.06	0.31	0.39	0.34	0.01
TONNAGE	1.42	0.12	1.30	11.30	3.65	7.65	3.77	0.09	3.68	11.33	2.79	1.33
RECOVERY (%)		78.94			93.94			98.72			87.00	
Iterative Calculation Results												
ASSAY	5.85	48.88	1.16	1.86	31.58	0.97	41.18	67.58	0.52	1.31	12.18	0.59
Sb TONNAGE	0.07	0.06	0.02	0.03	0.01	0.01	0.07	0.06	0.01	0.02	0.01	0.01
TONNAGE	1.42	0.12	1.30	1.39	0.04	1.35	0.16	0.09	0.06	1.41	0.09	1.33
wt% of ROF	100.00	8.30	91.70	97.92	2.84	95.08	11.14	6.67	4.48	99.56	6.23	93.33
RECOVERY (%)		78.94			49.24			98.72			57.77	

Overall Mass Balance for Test A, Standard Flowsheet, -25 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 6.02 , Overall flowsheet recovery = 84.05

Assays (%Sb):	ROF =	6.13	ROC =	48.98	ROT =	1.26
	(SRF)=	1.56	SRC =	23.78	SRT =	1.14
	CF =	35.38	CC =	66.48	CT =	4.34
	(SF) =	1.35	SC =	18.78	ST =	1.86

Initial Guess for recycle SC (mt) = 18.88

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	6.13	48.98	1.26	7.44	23.78	1.14	35.38	66.48	4.34	2.87	18.78	1.86
Sb TONNAGE	0.37	0.36	0.07	1.14	1.01	0.13	1.77	0.31	0.28	0.32	0.17	0.86
TONNAGE	6.02	0.74	5.28	15.28	4.27	11.01	5.01	0.47	4.54	15.55	1.64	5.55
RECOVERY (%)		81.97			80.95			93.84			54.26	
Iterative Calculation Results												
ASSAY	6.13	48.98	1.26	1.56	23.78	1.14	35.38	66.48	4.34	1.35	18.78	1.86
Sb TONNAGE	0.37	0.36	0.07	0.08	0.02	0.06	0.36	0.31	0.02	0.08	0.02	0.86
TONNAGE	6.02	0.74	5.28	5.45	0.18	5.35	0.84	0.47	0.37	5.72	0.17	5.55
wt% of ROF	100.00	12.29	87.71	90.56	1.67	88.89	13.96	7.76	6.28	95.09	2.85	92.24
RECOVERY (%)		81.97			28.12			93.84			23.75	

Overall Mass Balance for Test G, Regrind of Scavenger Concentrate and Cleaner Tails, 0-200 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 10.00 , Overall flowsheet recovery = 80.07

Assays (%Sb): ROF = 3.75 ROC = 44.10 ROT = 0.92
(SRF)= 1.50 SRC = 16.10 SRT = 1.00
CF = 21.90 CC = 64.30 CT = 3.03
(SF) = 1.14 SC = 6.90 ST = 0.44

Initial Guess for recycle SC (mt) = 10.00

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	0	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	3.75	44.10	0.92	3.15	16.10	1.00	21.90	64.30	3.03	1.43	6.90	0.44
Sb TONNAGE	0.60	0.52	0.15	0.04	0.61	0.23	1.09	0.60	0.16	0.39	0.20	0.00
TONNAGE	10.00	1.10	16.02	26.02	3.02	23.00	5.00	0.93	4.06	27.07	4.13	17.07
RECOVERY (%)		77.07			72.77			07.74			73.03	
Iterative Calculation Results												
ASSAY	3.75	44.10	0.92	1.50	16.10	1.00	21.90	64.30	3.03	1.14	6.90	0.44
Sb TONNAGE	0.60	0.52	0.15	0.30	0.12	0.10	0.42	0.60	0.04	0.22	0.14	0.00
TONNAGE	10.00	1.10	16.02	10.91	0.73	10.10	1.91	0.93	0.97	19.15	2.09	17.07
wt% of ROF	100.00	6.55	93.45	105.04	4.03	101.00	10.59	5.10	5.41	106.41	11.59	94.02
RECOVERY (%)		77.07			39.14			07.74			65.72	

Mass Balance for Test G, +149 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 3.87 , Overall flowsheet recovery = 25.92

Assays (%Sb):	ROF =	0.31	ROC =	36.50	ROT =	0.37
	(SRF)=	0.44	SRC =	35.50	SRT =	0.38
	CF =	11.80	CC =	51.20	CT =	2.50
	(SF) =	0.38	SC =	7.97	ST =	0.23

Initial Guess for recycle SC (mt) = 10.00

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	0.31	36.50	0.37	6.10	35.50	0.30	11.80	51.20	2.50	0.67	7.97	0.23
Sb TONNAGE	0.01	-0.00	0.01	0.01	0.78	0.03	0.26	0.00	0.05	0.09	0.06	0.01
TONNAGE	3.07	-0.01	3.08	13.00	2.19	10.09	2.10	0.00	2.10	13.07	0.74	3.07
RECOVERY (%)		-19.55			95.96			82.86			67.43	
Iterative Calculation Results												
ASSAY	0.31	36.50	0.37	0.44	35.50	0.30	11.80	51.20	2.50	0.30	7.97	0.23
Sb TONNAGE	0.01	-0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01
TONNAGE	3.07	-0.01	3.08	3.10	0.01	3.09	0.01	0.00	0.00	3.09	0.03	3.07
wt% of ROF	100.00	-0.17	100.17	101.10	0.40	100.70	0.24	0.16	0.00	100.70	0.93	99.84
RECOVERY (%)		-19.55			32.12			82.86			24.40	

Mass Balance for Test G, 188-149 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 2.21 , Overall flowsheet recovery = 82.15

Assays (%Sb):						
	ROF =	1.32	ROC =	55.88	ROT =	0.59
	(SRF)=	0.96	SRC =	43.78	SRT =	0.68
	CF =	21.48	CC =	68.28	CT =	6.48
	(SF) =	0.62	SC =	11.28	ST =	0.24

Initial Guess for recycle SC (mt) = 18.88

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	1.32	55.88	0.59	9.38	43.78	0.68	21.48	68.28	6.48	1.77	11.28	0.24
Sb TONNAGE	0.03	0.02	0.01	1.13	1.07	0.06	0.53	0.02	0.16	0.22	0.19	0.01
TONNAGE	2.21	0.03	2.18	12.18	2.46	9.72	2.49	0.04	2.45	12.17	1.78	2.17
RECOVERY (%)		55.89			94.85			78.43			88.31	
Iterative Calculation Results												
ASSAY	1.32	55.88	0.59	0.96	43.78	0.68	21.48	68.28	6.48	0.62	11.28	0.24
Sb TONNAGE	0.03	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.00	0.01	0.01	0.01
TONNAGE	2.21	0.03	2.18	2.26	0.02	2.24	0.05	0.04	0.01	2.25	0.08	2.17
wt% of ROF	100.00	1.32	98.68	102.21	0.85	101.37	2.17	1.88	0.37	101.74	3.54	98.20
RECOVERY (%)		55.89			37.83			78.43			62.69	

Mass Balance for Test G, 75-100 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 1.00 , Overall flowsheet recovery = 89.91

Assays (%Sb):						
	ROF =	3.04	ROC =	58.10	ROT =	0.76
	(SRF)=	1.23	SRC =	35.00	SRT =	0.74
	CF =	32.60	CC =	65.70	CT =	6.30
	(SF) =	0.01	SC =	11.40	ST =	0.32

Initial Guess for recycle SC (mt) = 10.00

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	3.04	58.10	0.76	9.79	35.00	0.74	32.60	65.70	6.30	2.17	11.40	0.32
Sb TONNAGE	0.06	0.04	0.01	1.15	1.09	0.06	1.02	0.05	0.19	0.26	0.22	0.01
TONNAGE	1.06	0.07	1.79	11.79	3.04	0.74	3.12	0.08	3.04	11.78	1.97	1.78
RECOVERY (%)		75.99			94.39			89.22			87.74	
Iterative Calculation Results												
ASSAY	3.04	58.10	0.76	1.23	35.00	0.74	32.60	65.70	6.30	0.01	11.40	0.32
Sb TONNAGE	0.06	0.04	0.01	0.02	0.01	0.01	0.03	0.05	0.00	0.02	0.01	0.01
TONNAGE	1.06	0.07	1.79	1.87	0.03	1.04	0.10	0.00	0.02	1.06	0.00	1.78
wt% of ROF	100.00	3.90	96.02	100.43	1.40	99.04	5.37	4.16	1.22	100.26	4.41	95.04
RECOVERY (%)		75.99			40.54			89.22			62.11	

Mass Balance for Test G, 44-75 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 2.61 , Overall flowsheet recovery = 89.29

Assays (%Sb): ROF = 4.48 ROC = 68.38 ROT = 0.99
(SRF)= 1.55 SRC = 34.98 SRT = 1.02
CF = 33.28 CC = 67.88 CT = 6.58
(SF) = 1.11 SC = 9.07 ST = 0.51

Initial Guess for recycle SC (mt) = 10.00

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	4.48	68.38	0.99	7.48	34.98	1.02	33.28	67.88	6.58	2.86	9.07	0.51
Sb TONNAGE	0.12	0.09	0.02	0.93	0.83	0.10	0.04	0.10	0.15	0.26	0.21	0.01
TONNAGE	2.61	0.15	2.46	12.46	2.37	10.08	2.53	0.15	2.37	12.46	2.26	2.46
RECOVERY (%)		79.28			88.96			88.95			79.78	
Iterative Calculation Results												
ASSAY	4.48	68.38	0.99	1.55	34.98	1.02	33.28	67.88	6.58	1.11	9.07	0.51
Sb TONNAGE	0.12	0.09	0.02	0.04	0.01	0.03	0.06	0.10	0.08	0.03	0.02	0.01
TONNAGE	2.61	0.15	2.46	2.64	0.04	2.60	0.20	0.15	0.04	2.64	0.10	2.46
wt% of ROF	100.00	5.80	94.12	101.15	1.59	99.56	7.47	5.90	1.57	101.13	7.03	94.10
RECOVERY (%)		79.28			35.38			88.95			57.86	

Mass Balance for Test G, 37-44 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 0.25 , Overall flowsheet recovery = 93.89

Assays (%Sb): ROF = 7.54 ROC = 61.28 ROT = 1.89
(SRF)= 1.79 SRC = 28.18 SRT = 1.17
CF = 32.48 CC = 69.18 CT = 5.38
(SF) = 1.33 SC = 7.84 ST = 0.58

Initial Guess for recycle SC (mt) = 10.00

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	7.54	61.28	1.89	7.69	28.18	1.17	32.48	69.18	5.38	2.59	7.84	0.58
Sb TONNAGE	0.02	0.02	0.00	0.79	0.71	0.00	1.15	0.02	0.19	0.27	0.22	0.00
TONNAGE	0.25	0.03	0.22	10.22	3.52	6.70	3.55	0.03	3.52	10.22	2.84	0.22
RECOVERY (%)		87.89			90.03			90.59			83.84	
Iterative Calculation Results												
ASSAY	7.54	61.28	1.89	1.79	28.18	1.17	32.48	69.18	5.38	1.33	7.84	0.58
Sb TONNAGE	0.02	0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00
TONNAGE	0.25	0.03	0.22	0.25	0.01	0.24	0.03	0.03	0.01	0.25	0.03	0.22
wt% of ROF	100.00	10.73	89.27	99.59	3.26	96.33	13.99	10.16	3.83	100.16	10.32	89.84
RECOVERY (%)		87.89			36.76			90.59			68.82	

Mass Balance for Test G, 25-37 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 1.03 , Overall flowsheet recovery = 94.47

Assays (%Sb):						
	ROF =	6.12	ROC =	56.30	ROT =	1.17
	(SRF)=	2.07	SRC =	16.30	SRT =	1.20
	CF =	20.30	CC =	67.50	CT =	4.30
	(SF) =	1.39	SC =	6.02	ST =	0.37

Initial Guess for recycle SC (mt) = 10.00

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	6.12	56.30	1.17	6.34	16.30	1.20	20.30	67.50	4.30	2.26	6.02	0.37
Sb TONNAGE	0.06	0.05	0.01	0.69	0.61	0.09	1.00	0.06	0.16	0.25	0.22	0.00
TONNAGE	1.03	0.09	0.94	10.94	3.72	7.22	3.01	0.09	3.72	10.94	3.20	0.94
RECOVERY (%)		82.60			87.50			90.50			80.39	
Iterative Calculation Results												
ASSAY	6.12	56.30	1.17	2.07	16.30	1.20	20.30	67.50	4.30	1.39	6.02	0.37
Sb TONNAGE	0.06	0.05	0.01	0.02	0.01	0.01	0.04	0.06	0.00	0.02	0.01	0.00
TONNAGE	1.03	0.09	0.94	1.11	0.06	1.05	0.16	0.09	0.07	1.12	0.18	0.94
wt% of ROF	100.00	8.98	91.02	108.17	6.20	101.97	15.10	8.57	6.62	108.59	17.15	91.43
RECOVERY (%)		82.60			45.25			90.50			77.57	

Mass Balance for Test G, -25 micron particles

Bases; 1 hour of operation, Feed (mt/hr) 6.97 , Overall flowsheet recovery = 84.98

Assays (%Sb):	ROF =	5.35	ROC =	41.38	ROT =	1.63
	(SRF)=	2.16	SRC =	12.78	SRT =	1.39
	CF =	19.38	CC =	63.68	CT =	3.18
	(SF) =	1.54	SC =	4.31	ST =	0.87

Initial Guess for recycle SC (mt) = 10.00

	ROF	ROC	ROT	SRF	SRC	SRT	CF	CC	CT	SF	SC	ST
STREAM NO.	8	9	10	10+17	11	12	13	15	14	16	17	18
FROM		1	1	4	5	5	2	3	3	6	6	7
TO	1	2	4	5	2	6	3		6	7	4	
Initial Calculation Results												
ASSAY	5.35	41.38	1.63	3.27	12.78	1.39	19.38	63.68	3.18	1.69	4.31	0.87
Sb TONNAGE	0.37	0.27	0.10	0.53	0.34	0.19	0.65	0.32	0.09	0.28	0.17	0.06
TONNAGE	6.97	0.65	6.32	16.32	2.72	13.60	3.37	0.50	2.87	16.47	3.92	6.47
RECOVERY (%)		72.39			64.59			88.24			60.72	
Iterative Calculation Results												
ASSAY	5.35	41.38	1.63	2.16	12.78	1.39	19.38	63.68	3.18	1.54	4.31	0.87
Sb TONNAGE	0.37	0.27	0.10	0.17	0.07	0.10	0.23	0.32	0.02	0.12	0.07	0.06
TONNAGE	6.97	0.65	6.32	7.87	0.54	7.34	1.19	0.50	0.69	8.03	1.56	6.47
wt% of ROF	100.00	9.30	90.62	112.97	7.69	105.28	17.07	7.14	9.93	115.21	22.35	92.86
RECOVERY (%)		72.39			40.84			88.24			54.39	